COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

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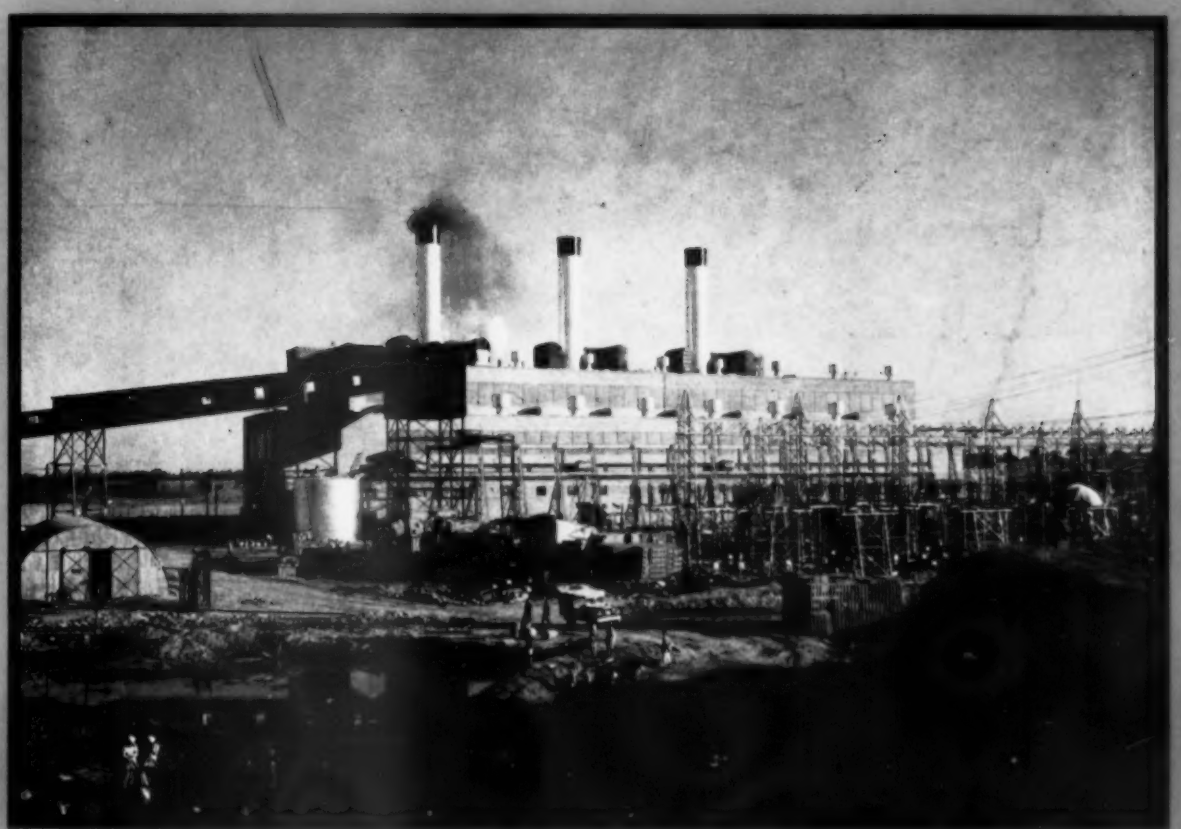


Bokaro—India's newest and largest power station; see page 64

Carbide Segregation and Decarburization in Welded Joints ▸

Outage Classification in Power Systems ▸

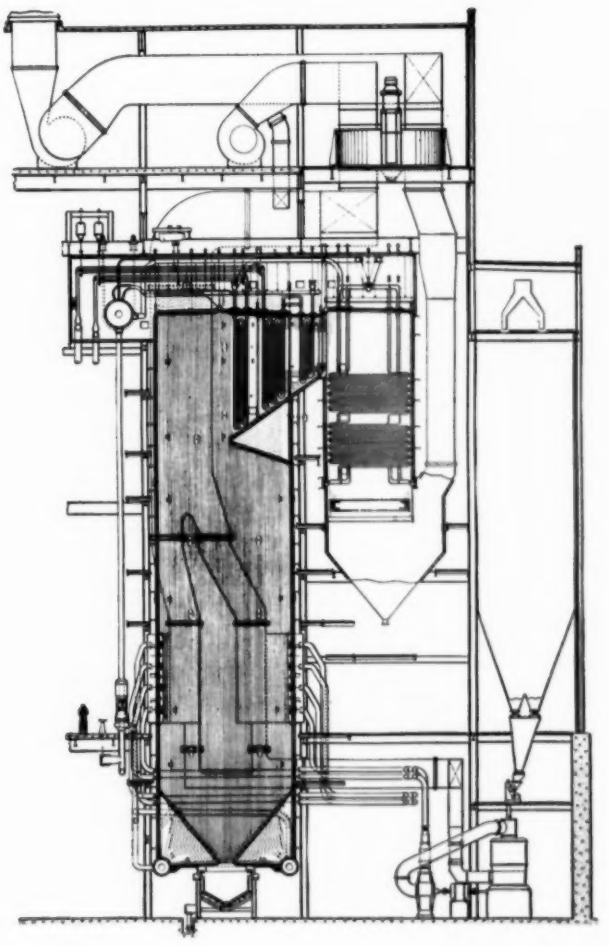
Electrostatic Precipitators ▸

Steam Tables up to 700 C ▸

BUCK STEAM STATION

Duke Power Company

C-E controlled circulation boilers



The C-E Unit shown above is one of two duplicates now in process of fabrication for the Buck Steam Station, Spencer, N. C., of the Duke Power Company.

Each of these units is designed to serve a 125,000 kw turbine-generator operating at a throttle pressure of 1800 psi with a primary steam temperature of 1000 F, reheated to 1000 F.

These units are of the controlled-circulation, radiant type with a reheater section located between the primary and secondary superheater surfaces. An economizer section follows the rear superheater section and regenerative type air heaters follow the economizer surface.

Pulverized coal firing is employed, using bowl mills and tilting, tangential burners.

B-594

C-E

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200 Madison Avenue, New York 16, N. Y.

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COMBUSTION

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Vol. 24 **No. 9**

March 1953

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CCA

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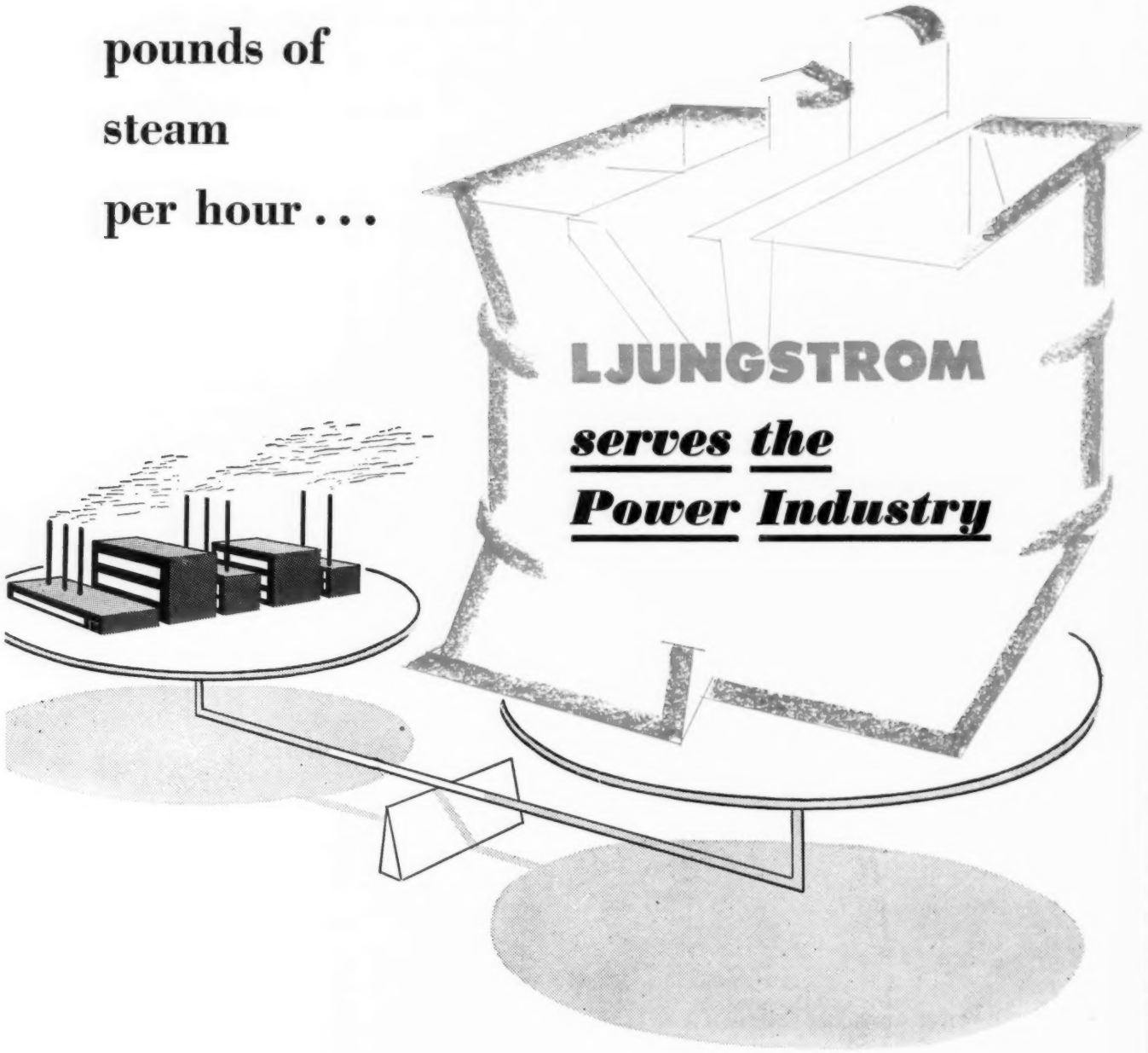
347,000,000

pounds of steam per hour . . .



In the post-war rush to expand power generating facilities, utilities have not lost sight of the need for *operating economy*. Increasingly over these years, the fuel-saving, performance-improving potentials of the Ljungstrom Air Preheater have been realized – until today, nearly two out of every three power boilers are ordered with the specification "Ljungstom Air Preheater."

Since 1946 alone, in fact, more than 347,000,000 pounds per hour of steam capacity – installed or on order – have been designed for Ljungstrom.

This record speaks for itself. It proves that the Ljungstrom Air Preheater is, indeed, *the most economical heating surface in the modern boiler.*

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Editorials

International Steam Table Conferences

Publication within the past four years of new steam tables in Great Britain, Germany, Japan and Russia points to the desirability of holding another International Steam Table Conference along the lines of those conducted in 1929, 1930 and 1934. A recent article by H. Erythropel in *Zeitschrift, VDI*, a translation of which appears in this issue, reveals substantial discrepancies among the various tables, particularly for values of enthalpy of superheated steam. This is suggestive of one of the major problems of the Third International Steam Table Conference. In the October 1934 issue of this publication Dr. Joseph H. Keenan of the Massachusetts Institute of Technology reported as follows: "Enthalpy of superheated steam proved to be the most troubled water the American Conference had to navigate. At the bottom the difficulty was excessive data. There were direct measurements by the condensation method. . ., specific heat measurements . . . and values deduced from specific volume measurements. . . . Attached to each of these was the pride and aspiration of a nation, and compromise gave pain to patriotism. Nevertheless, agreement was reached and tolerances approximately one-third as large as those at the 1929 London Conference were established."

As steam conditions in central stations push higher and higher, the validity of steam tables, and particularly their reliability for use in heat-balance computations, becomes of ever-increasing importance. In the past The American Society of Mechanical Engineers has shown considerable interest in comprehensive research of the properties of steam, as also have mechanical engineering groups in other countries. Some means should be found to reconvene interested steam-table authorities into a Fourth International Steam Table Conference. Its benefits would be in keeping with the following comments from an editorial in these columns in September 1934:

"It has been said that engineering knows no national borders, yet economic conditions in different countries exert a strong influence on engineering practice. On the other hand, the properties of steam are universal, and, granting equal accuracy of observations, discrepancies in the results of different investigators must be attributable to methods. That the values are likely to be brought into line for all practical purposes represents a monumental accomplishment well worth the money and effort put into the work."

Men, Machines and Economics

In an editorial entitled "The Art of the Practical Engineer" which appeared last month, the comment was made that it is difficult and perhaps undesirable to draw a sharp distinction between the art and the science of engineering. Another area which is inseparable from engineering is that of economics, for engineering decisions inherently have economic consequences. The engineer should be aware of the financial ramifications of his activities in order to maintain them in proper balance with his strictly technical endeavors. And on occasion it may be well for him to take time from his daily activities to review some of the fundamental concepts of the economic system under which he functions.

A recent book entitled "Big Business: A New Era" by David Lilienthal, former head of TVA and the Atomic Energy Comission, offers some challenging thoughts on the economic role of large industrial enterprises and their relation to the overall national interest. The following excerpts are typical of some of the basic reasoning set forth:

"The purpose of our economic society and system is to promote freedom for the individual, as one prime essential of happiness and human fulfillment. . . . Freedom of choice in economic matters means freedom to choose between competing ideas or services or goods. It means the maximum freedom to choose one job or one profession or one line of business as against some other. . . . . .

"These are economic choices. They are, however, more than economic or business acts. They are the mark of men who are free, as free as in society it is possible or workable for men to be. We call our economic system, quite appropriately, free enterprise. To maintain and nourish the essentials of free enterprise for all our people we must maintain and nourish the freedom of choice that makes the system come into being and flourish."

Mr. Lilienthal succeeds in showing the interrelationship of technological developments and the growth of large enterprises. Instead of being fearful of the consequences of this interrelationship, he is hopeful that man can control his machines in such a manner as to build a new kind of freedom of benefit to all. To the engineer who is concerned with the design of equipment and the formulation of new projects, this book may serve to re-emphasize the inseparability of engineering and its economic consequences.

Local Carbide Segregation and Decarburization in Welded Joints

The following reports the results of a cooperative investigation by the M. W. Kellogg Company and The Detroit Edison Company in which 1 1/4 per cent chrome – 1/2 per cent molybdenum, ASTM A-158, Grade P11 piping was involved.

By H. S. BLUMBERG*

and I. A. ROHRIG†

LATE in 1951 it was reported at an industry meeting[1] that an investigation of a welded joint in ASTM A-158, Grade P11 (1 1/4 Cr – 1/2 Mo) pipe removed from a main steam line, which had been in high temperature service at 1000 F for less than a year, disclosed the occurrence of carbide segregation and decarburization at the weld junction. The band was stated to be adjoined by a carbide-free area, consisting of a wholly ferritic zone. In some cases the carbide segregation appeared as an almost unbroken band of pearlite along the edge of the weld at the junction with the heat-affected zone. It was suspected that this phenomenon might occur only in those intermediate low chromium-molybdenum alloy steels containing higher silicon contents (0.50 to 1.00 per cent) as in P11 pipe. It was believed that, using the same welding electrodes and heat treatment, carbide segregation does not occur when silicon is present in the lower range (0.50 per cent maximum) with chromium and molybdenum within the chemistry range of P11 material.

The reported occurrence became the cause of serious concern to power plant operators, particularly those who had recently placed P11 steel pipe in high-temperature service, as well as those who had specified that composition for proposed installations.

Scope of Investigation

The Detroit Edison Company and The M. W. Kellogg Company decided to undertake a cooperative investigation of the phenomenon. In a joint review of the problem the cooperators at once agreed that there are a great many variables involved. It was recognized that a complete investigation of all of these would extend the program far beyond the time which should be allowed to furnish industry with some assurance as to the suitability of welded joints currently in service or those now being fabricated. The investigation was therefore planned to obtain data regarding: (*a*) the conditions under which carbides segregation and decarburization occur in P11 steel, (*b*) the effect of this occurrence on the properties of the welded joint and (*c*) information as to prevention of the occurrence of this phenomenon in welded joints before they enter service. Accordingly the following three major factors were given primary consideration:

Factor	Variables Considered
Silicon content of A-158, P11 pipe (1 1/4 Cr–1/2 Mo)	Low-silicon steel, high-silicon steel
Welding electrodes	Three compositions of weld deposits. Four types of electrode coatings.
Heat treatments	Eight heat treatments including the "as-welded" condition

Each company proceeded to make independent metallurgical studies. When the data were available they were considered jointly. As here reported, emphasis was given to the significance of the findings to users of welded construction in P11 grade steel in steam power plant service.

Materials Investigated

The materials used by the two companies for this investigation consisted of pipe and welding electrodes. The pipe materials are listed in Table 1. These materials were furnished by National Tube Company and conform to ASTM Specification A-158, Grade P11 (1 1/4 Cr – 1/2 Mo), with silicon contents respectively near the minimum and maximum of the allowable range which is 0.50 to 1.0 per cent. Unfortunately the pipe producer was able to furnish only sufficient length of

TABLE 1—PIPE MATERIALS USED FOR TEST

Pipe Mark	Size, In. Diameter	Size, In. Thickness	Chemical Composition C	Mn	Si	Cr	Mo
(a)	10 3/4	1 1/8	0.10	0.68	0.68	1.32	0.54
(b)	5 9/16	3/4	0.06	0.42	0.97	1.23	0.50

NOTE: Pipe (a) was used by the M. W. Kellogg and The Detroit Edison Company; pipe (b) was used by the M. W. Kellogg Company only.

TABLE 2—ELECTRODES USED FOR TEST

Electrode mark*	Weld Identity	Deposit Composition, Nominal	Type of Electrode Coating, ASTM A-316 Class	Description
A	1-A, 2-A	1.25 Cr – 0.50 Mo	16	Low-hydrogen, potassium
B	3-B	2.25 Cr – 1.0 Mo	16	Low-hydrogen, potassium
C	4-C	1.0 Cr – 0.50 Mo	10	High cellulose, sodium
D	4-D	1.0 Cr – 0.50 Mo	13	High titania, potassium
E	5-E	1.0 Cr – 0.50 Mo	16	Low-hydrogen, potassium
F	5-F	1.0 Cr – 0.50 Mo	15	Low-hydrogen, sodium
G	6-G	1.0 Cr – 0.50 Mo	..	Partially lime-ferritic and titania-potassium†
H	6-F	2.25 Cr – 1.0 Mo	..	Partially lime-ferritic and titania-potassium†

* Electrodes A and B were used in the test welds made by The M. W. Kellogg Company; Electrodes C, D, E, F, G and H were used in test welds made by The Detroit Edison Company.
† Coating was not of a type included in ASTM A-316.

[1] A meeting of the EEI-AEIC Joint Committee on the use of Metals at High Temperatures.

* Chief Metallurgist, the M. W. Kellogg Company, Jersey City, N. J.
† Senior Research Engineer, Engineering Laboratory, The Detroit Edison Company, Detroit, Mich.

the higher silicon material for a single circumferential weld. Deoxidation practice in melting was stated by the manufacturer to include the addition of less than one-half pound of aluminum per ton.

Eight welding electrodes were used, as listed in Table 2. Of these, five were 1 Cr – $^1/_2$ Mo grades, one $1^1/_4$ – $^1/_2$ Mo, and two $2^1/_4$ Cr–1 Mo. All the 1 Cr – $^1/_2$ Mo electrodes were used by the Detroit Edison Company, the one $1^1/_4$ Cr – $^1/_2$ Mo electrode by The M. W. Kellogg and one $2^1/_4$ Cr – 1 Mo electrode by each cooperator.

Procedure

The Detroit Edison Company

Three complete welded joints were made. The pipe material was preheated to 500–700 F before welding and was maintained in that temperature range during welding by means of electric-resistance type heaters. The welds were made in a fixed horizontal position. Measured from the top of the pipe, half of the circumference of each weld was made with one of the different electrodes mentioned in Table 2 and the other half with another; that is, in making the three welds, six different electrodes, C through H, Table 2, were used.

Three $^1/_2$-in.-wide strips were cut across the respective parts of the welds made with one of each of the six different welding electrodes. One of the strips was stress-relieved at 1300 F for two hours and then used for a bend test. The other strips were given the postwelding heat treatments shown in Table 3, and then were used for metallographic examination and hardness tests.

The M. W. Kellogg Company

Three welds were prepared, designated as 1-A, 2-A, and 3-B in Tables 2 and 3. The pipe was preheated to 400–500 F before welding and maintained in that temperature range during welding. The pipes were rotated during welding so that all welding was done in the downhand position. Welds 1-A and 2-A were made respectively, in low- and high-silicon base metal, both being joined with the same lot of $1^1/_4$ Cr – $^1/_2$ Mo electrodes. Strips were cut across the welds and then subjected to the heat treatments listed in Table 3 for these welds.

Weld 3-B consisted of low-silicon $1^1/_4$ Cr–$^1/_2$ Mo base metal welded with a deposit of $2^1/_4$ Cr – 1 Mo electrodes. Weld 3-B was given an immediate partial postheat treatment after welding, consisting of one hour holding at 1300 F, followed by furnace cooling. The weld was then sectioned and given the heat treatments listed for this weld in Table 4. The strips of each weld in each condition of heat treatment were subjected to the following tests, in so far as material was available:

Tension tests
Bend tests
Charpy impact tests (slotted at junction weld—heat-affected zone, where carbide segregation and decarburization were reported)
Hardness exploration
Microscopic examination

Results Obtained

The Detroit Edison Company

Guided-bend tests made on the stress-relieved strips representing the welds from the six different lots of electrode showed satisfactory bend results with no sign of serious cracking. The welds produced by three of the electrodes, 4-C, 5-E and 5-F, showed no defects of any type whereas the other three had varying degrees of small pinholes and fissures.

Hardness tests made in the weld metal in the heat affected zone, and in the base metal of each weld joint after the five conditions of heat treatment, including the as-welded condition, showed no unusually high hardness values in any of the 1 Cr – $^1/_2$ Mo deposits. As would be expected, the $2^1/_4$ Cr – 1 Mo welded joint had high hardness in the as-welded and the normalized conditions but these hardnesses were lowered considerably by heat treatments to a degree known from past experience to be consistent for these welds.

The results of metallographic observations on specimens from each of the six welds after each of the five heat treatments are contained in Table 4, in which there is given a rating for carbide segregation and decarburiza-

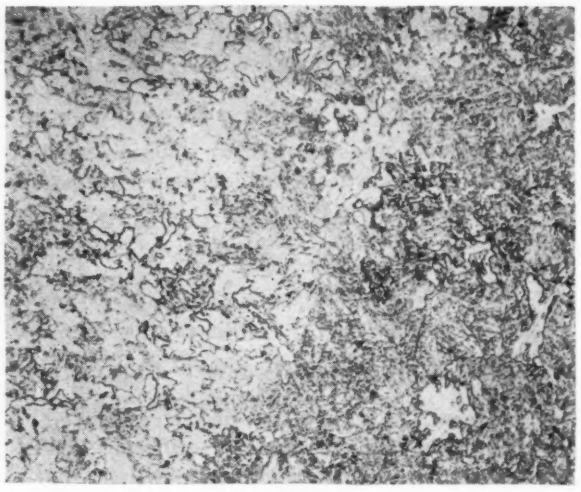
TABLE 3—HEAT-TREATMENT OF TEST WELDS

Treatments	Welds Treated
No treatment (as-welded)	1-A, 2-A, 4-C, 4-D, 5-E, 5-F, 6-G and 6-H
1300 F, 1 hr, Furnace Cool	1-A, 2-A, 3-B, 4-C, 4-D, 5-E, 5-F, 6-G and 6-H
1300 F, 2 hr, Furnace Cool	3-B
1450 F, 1 hr, Furnace Cool	1-A, 2-A, 3-B
1550 F, 1 hr, Furnace Cool	1-A, 2-A, 3-B, 4-C, 4-D, 5-E, 5-F, 6-G and 6-H
1700 F, 1 hr, Furnace Cool	1-A, 2-A, 3-B, 4-C, 4-D, 5-E, 5-F, 6-G and 6-H
1700 F, 1 hr, Air Cool	3-B
1300 F, 1 hr, Furnace Cool	
1700 F, 1 hr, Air Cool	4-C, 4-D, 5-E, 5-F, 6-G and 6-H

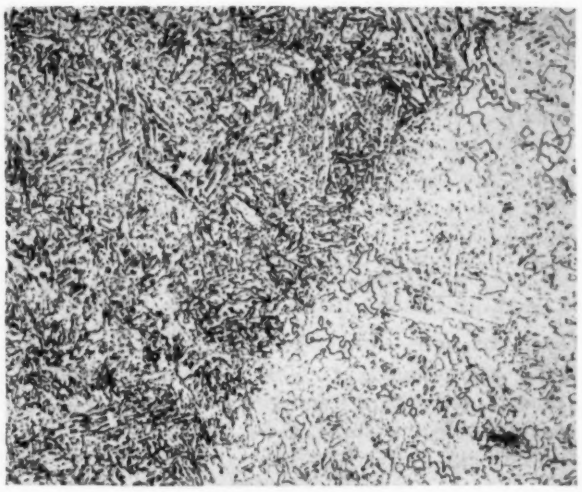
TABLE 4—SUMMARY OF METALLOGRAPHIC OBSERVATIONS

(Numbers in parentheses represent the number of welded joints for each condition indicated)

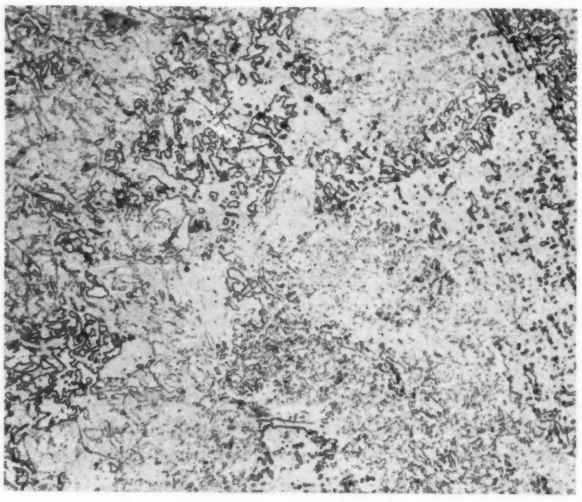
Heat Treatment	1 Cr – $^1/_2$ Mo Welds		$1^1/_4$ Cr – $^1/_2$ Mo Welds		$2^1/_4$ Cr – 1 Mo Welds	
	Carbide Segregation	Decarburization	Carbide Segregation	Decarburization	Carbide Segregation	Decarburization
As-welded	None (5)	None (5)	None (2)	None (2)	None (1)	Slight (1)
1300 F, 1 hr, F.C.	None (5)	None (5)	None (2)	None (2)	None (2)	Slight (1) Moderate (1)
1300 F, 2 hr, F.C.	....	....	...	...	Slight (1)	Moderate (1)
1450 F, 1 hr, F.C.	....	....	None (2)	None (2)	Moderate (1)	Strong (1)
1550 F, 1 hr, F.C.	None (1) Slight (2) Moderate (2)	Slight (2) Moderate (2) Strong (1)	None (1) Slight (1)	Slight (2)	Moderate (1) Strong (1)	Strong (2)
1700 F, 1 hr, F.C.	None (1) Slight (1) Moderate (2) Strong (1)	Slight (1) Moderate (3) Strong (1)	Strong (2)	Strong (2)	Strong (2)	Strong (2)
1700 F, 1 hr, A.C.	None (5)	None (4) Slight (1)	...	...	None (1)	Slight (1)
1700 F, 1 hr, A.C. 1300 F, 1 hr, F.C.	....	....	None (2)	None (2)	Slight (1)	Moderate (1)
No. of welds made	5		2		2	
Weld electrodes	1.0 Cr – 0.50 Mo		1.25 Cr – 0.50 Mo		2.25 Cr – 1.0 Mo	
Pipe material	$10^3/_4$ in. diameter (low silicon)		1—$5/_{16}$ in. diam (high Si) 1—$10^3/_4$ in. diam (low Si)		$10^3/_4$ in. diam (low silicon)	
Weld identity	The Detroit Edison Company, five welds		M. W. Kellogg Company, two welds		The Detroit Edison Company, M. W. Kellogg Company—one weld each	



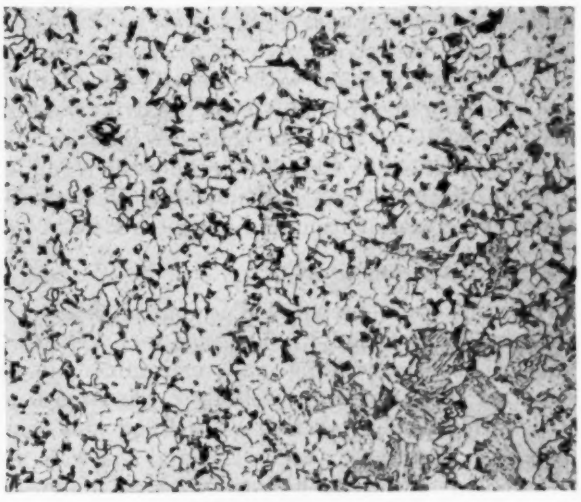
As Welded



1550 F, 1 Hour F.C.

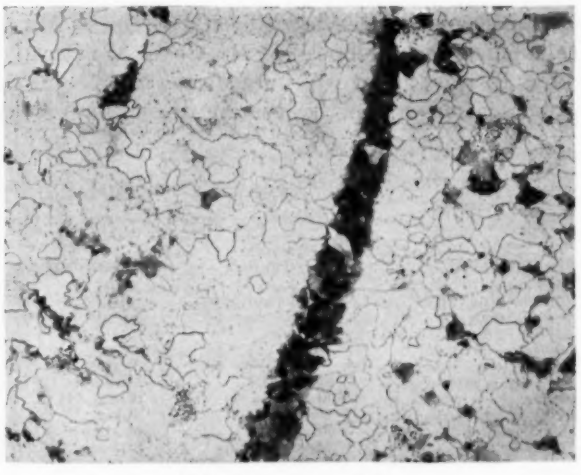


1300 F, 1 Hour, F.C.



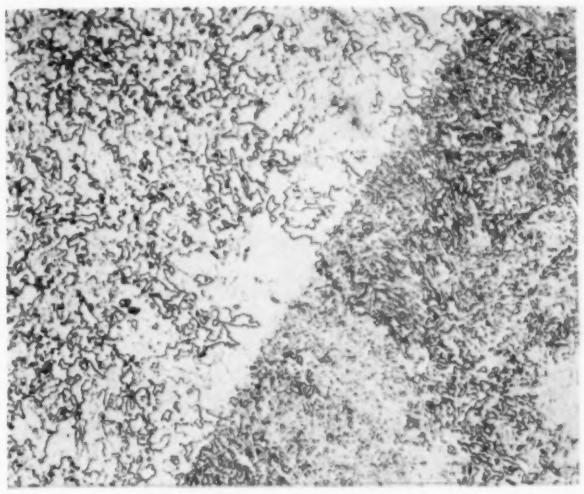
1700 F, 1 Hour, A.C.
1300 F, 1 Hour, F.C.

1450 F, 1 Hour, F.C.

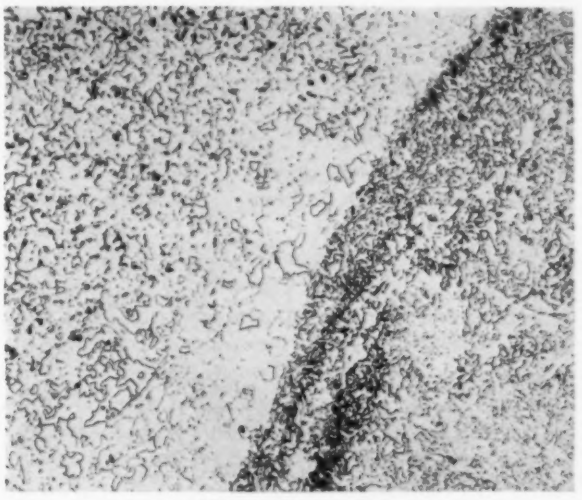


1700 F, 1 Hour, F.C.

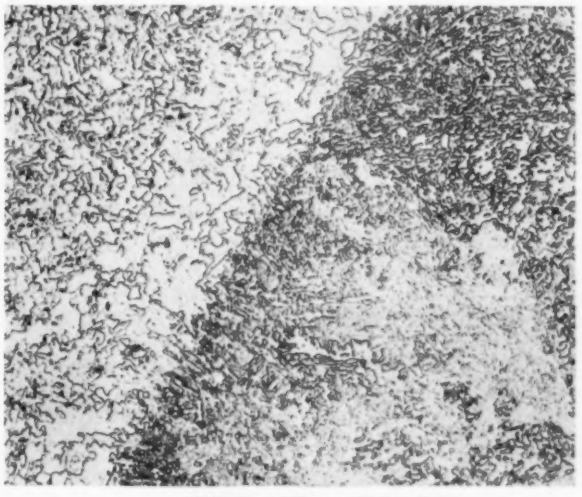
Fig. 1—Microstructure of representative weld cross-sections between low-silicon 1.25 Cr—0.50 Mo pipe welded with 1.25 Cr—0.50 Mo electrodes. Weld is on the right-hand size, junction is in the center. Photomicrographs at 100X



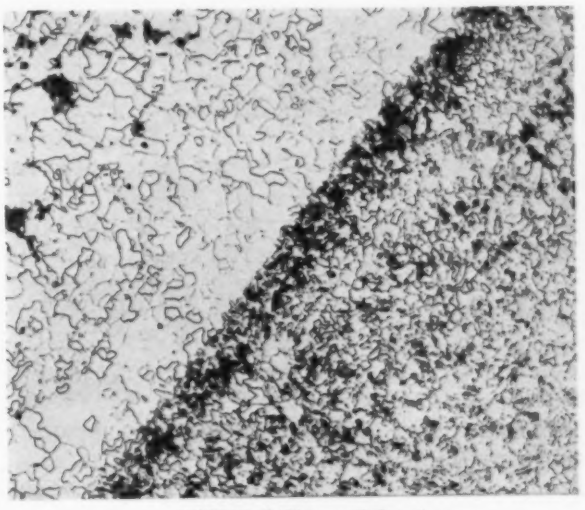
1300 F, 1 Hour, F.C.



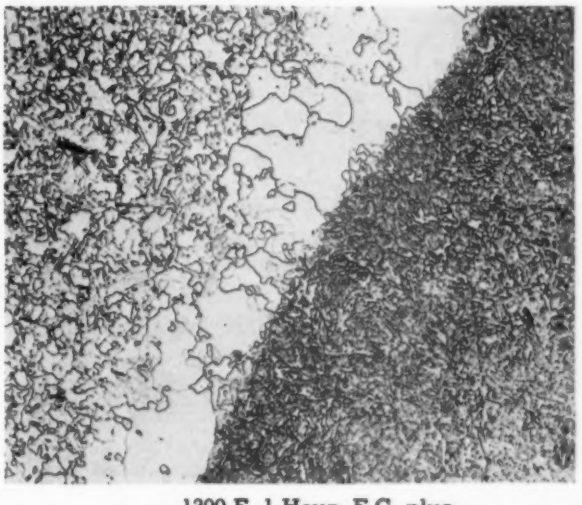
1300 F, 1 Hour, F.C. plus
1550 F, 1 Hour, F.C.



1300 F, 1 Hour, F.C. plus
1300 F, 1 Hour, F.C.



1300 F, 1 Hour, F.C. plus
1700 F, 1 Hour, F.C.



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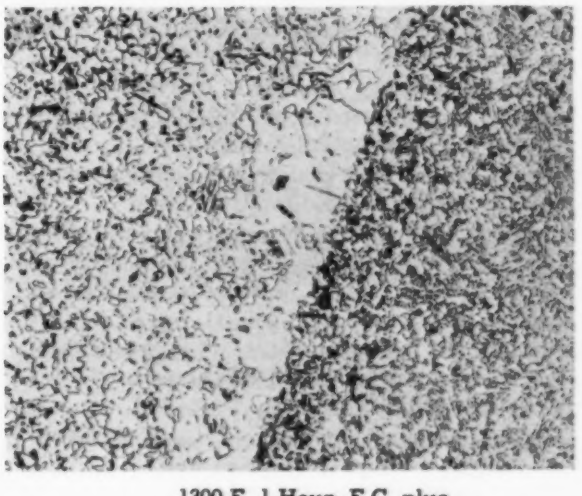


1300 F, 1 Hour, F.C. plus
1700 F, 1 Hour, A.C. plus
1300 F, 1 Hour, F.C.

Fig. 2—Microstructure of representative weld cross-sections between low-silicon 1.25 Cr—0.50 Mo pipe welded with 2.25 Cr—1.0 Mo electrodes. Weld is on the right-hand side, junction is in the center. Photomicrographs at 100X.

tion. Grade P11 pipe material, when welded with either of the five different 1 Cr – $^1/_2$ Mo electrodes used in the Detroit Edison test, showed no decarburization adjacent to the weld deposit either in the as-welded condition or after postweld heat treatment at 1300 F. However, if postweld heat-treated at 1550 F or higher, a decarburized zone occurred in the P11 pipe metal adjacent to the 1 Cr – $^1/_2$ Mo weld deposit.

Grade P11 pipe material, when welded with the one $2^1/_4$ Cr – 1 Mo electrode used in the Detroit Edison test, showed a decarburized zone approximately 0.025 to 0.050 in. wide adjacent to the weld deposit in the as-welded condition and after postweld heating at 1300 F for stress-relief. The decarburized zone became more prominent after the samples had been annealed at either 1550 F or 1700 F. The finding that decarburization can occur in Grade P11 pipe material welded with 2.25 Cr – 1 Mo weld metal and post weld annealed at 1550 F is in agreement with the results reported at the EEI-AEIC meeting.

THE M. W. KELLOG COMPANY

Tension tests representing each of the three welds in the various conditions of heat treatment listed in Table 4 showed strengths consistent with the heat treatments to which they were subjected. In general, welds made with the $1^1/_4$ Cr – $^1/_2$ Mo electrodes and heat-treated below the critical range fractured in the base metal, whereas those treated within and above the critical range broke in the weld metal. All specimens from the $2^1/_4$ Cr – 1 Mo welds fractured outside the weld as would be expected from the higher strength of this higher chromium-molybdenum composition. Two important observations are that in no case did any fracture occur in the region where carbide segregation or decarburization had occurred, also that all tension-test fractures were accompanied by a high degree of deformation.

Bend tests were made only on weld joints produced with $1^1/_4$ Cr – $^1/_2$ Mo electrodes. No failures were obtained in any of the tests, i.e., no zone of weakness was found in any region in these welds where carbide segregation and decarburization were discovered microscopically. No bend tests were made on the $2^1/_4$ Cr – 1 Mo weld.

Charpy-impact test specimens notched at the junction of the heat-affected zone and the weld gave high values and disclosed no indication of weakness.

Hardness values obtained were consistent with those reported by the Detroit Edison Company.

Data pertaining to carbide segregation and decarburization are given in Table 4. Typical photomicrographs are shown in Figs. 1 and 2. In both the low- and the high-silicon-base-metal weld joints, 1-A and 2-A, made with $1^1/_4$ Cr – $^1/_2$ Mo electrodes, no appreciable carbide segregation or decarburization was noted at the junction of the weld and the heat-affected zones after treatments at 1300 F and 1450 F. However, after a slow cool from 1550 F, slight carbide segregation and decarburization were noted in both welds. "Strong" effects were noted in both welds upon annealing (furnace cooling from 1700 F) whereas no appreciable effects were observed when the heat treatment consisted of normalizing (air cooling from 1700 F) followed by stress relieving from 1300 F. Both low- and high-silicon-base metal welds made with electrodes of similar composition thus show nearly similar microstructural behavior after the various heat treatments.

A greater degree of carbide segregation and decarburization was observed when welding of $1^1/_4$ Cr– $^1/_2$ Mo base metal was done with the "dissimilar" deposit of $2^1/_4$ Cr – 1 Mo composition. It will be observed in Table 4 that the $2^1/_4$ Cr – 1.0 Mo weld showed some effect after any of the heat treatments used.

Discussion

The data presented in Table 4 represent observations made on 48 specimens from welds made with nine different electrodes which deposited three separate weld metal compositions. The effect of eight heat treatments is also considered. The data are evidence regarding the the occurrence of carbide segregation and decarburization in the P11 pipe material invesitgated.

It was noted that when carbide segregation takes place, it occurs very close to the junction of the weld and base metal but on the weld metal side. The depletion of carbon appears mostly on the base metal side of the weld.

Date available for the 1 Cr – $^1/_2$ Mo and $1^1/_4$ Cr – $^1/_2$ Mo deposits indicate that carbide segregation or decarburization does not occur in either the "as-welded" condition, after a stress relief at 1300 F, or after stress relief at 1450 F. The occurrence of a moderate degree of segregation and decarburization in the pipe material itself is apparent with this type of weld metal after a furnace cool from 1550 F and is most pronounced after a furnace cool from 1700 F. It is unlikely that the 1700-F heat treatment would be used for welded joints in these materials. The 1 Cr – $^1/_2$ Mo and $1^1/_4$ Cr – $^1/_2$ Mo weld joints show a negligible amount of decarburization or carbide segregation after normalizing from 1700 F, or when that treatment is followed by a stress relief at 1300 F.

From the tests made with $2^1/_4$ Cr – 1 Mo deposits, it appears that in the "as-welded" condition no carbide segregation is present. However, after a stress relief at 1300 F and higher, moderate to strong effects are observed. The most severe results were noted after annealing from 1700 F. It is thus indicated that if carbide segregation at the weld junction is to be prevented, $2^1/_4$ Cr – 1 Mo electrodes should not be used, unless the heat treatment consists of normalizing at 1700 F followed by stress relieving at about 1300 F. However, it must be pointed out that there is no evidence to indicate that carbide segregation and decarburization present in the greatest degree observed is harmful for service.

No difference was observed metallographically between the weld made in the high silicon pipe material and the low silicon steels. Evidently the silicon content of the pipe materials had no effect in promoting or suppressing carbide segregation.

Tension, bend and impact tests made at room temperatures disclosed no brittleness or other weakness, even in those welds containing the most severe carbide banding and decarburization. This may be considered of prime significance as indicating that when the maximum degree of segregation observed in the tests is present in welds there is little cause for alarm.

It may be questioned whether the observed micro-

structures will remain stable in service. In an effort to obtain data on this point, this investigation will be continued with a study of the effect of time.

Conclusions

1. Carbide segregation and accompanying decarburization may occur, under some conditions, at the junction of the weld and heat-affected zone of ASTM A-158, P11 ($1^1/_4$ Cr – $^1/_2$ Mo) steel welded joints.

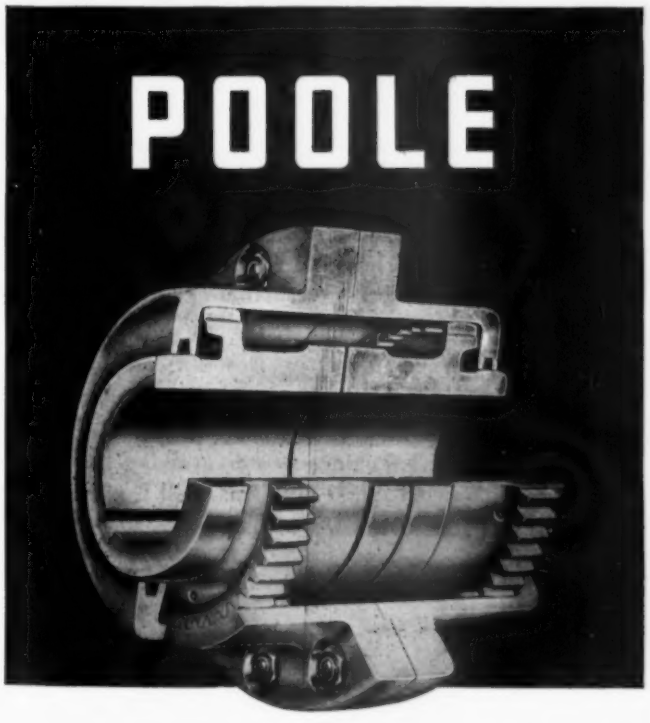
2. In welded joints of which the composition with regard to carbon, chromium and molybdenum is nearly similar in both weld and base metal, no appreciable carbide segregation appears to occur when postwelding heat treatment temperatures are below the lower critical temperature.

3. When the chromium and molybdenum contents of weld metal are appreciably higher than in the base metal, slight carbide segregation and decarburization begin to occur with a heat treatment involving slow cooling at 1300 F or higher, increasing in degree as the heat-treating temperature is raised.

4. Slow cooling from above the upper critical temperature yields the greatest degree of carbide segregation.

5. Air cooling from above the upper critical temperature inhibits carbide segregation, even when followed by stress relief at 1300 F.

6. With even the most severe carbide segregation and decarburization observed, there was no indication of embrittlement or weakness at the junction, as judged by room temperature laboratory tests.



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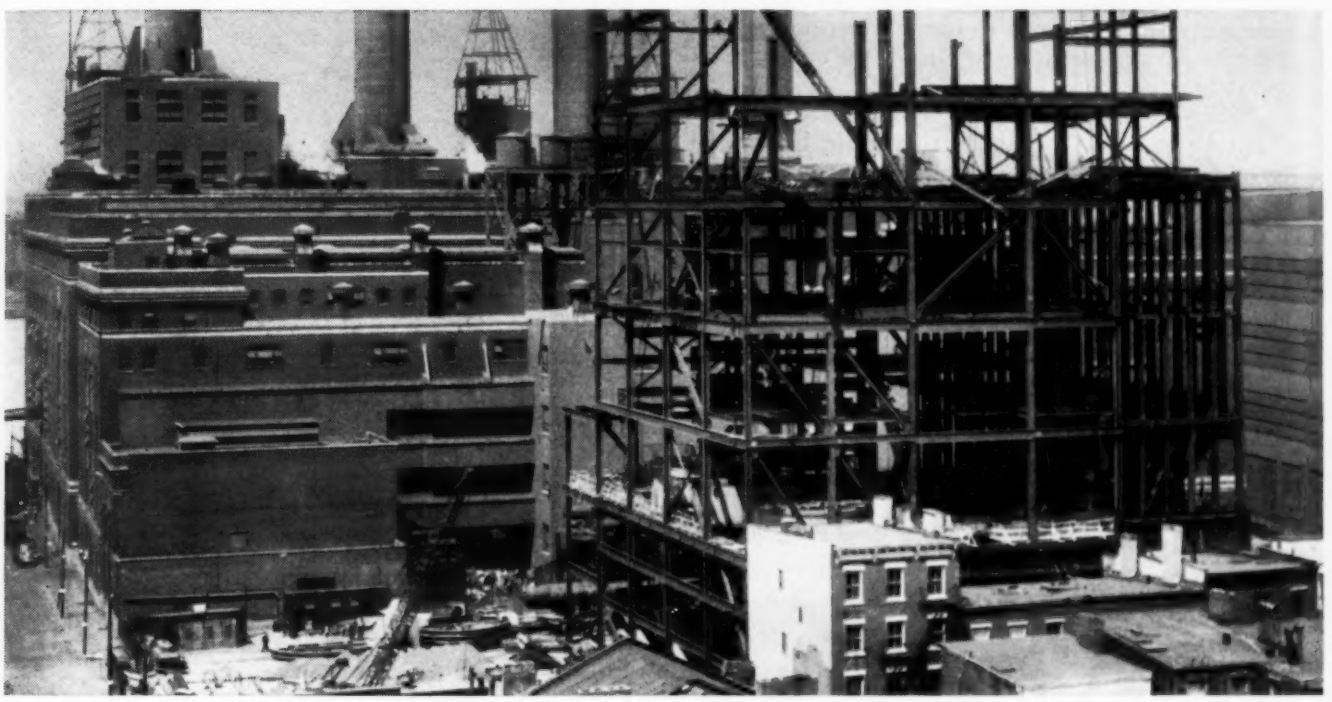

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A Classification of Outages of Facilities in Electric Power Systems

Lack of uniformity in nomenclature has tended to detract from the usefulness of terms relating to outages in power facilities. This article represents a well-planned effort to devise a common terminology made up of precise definitions which are logically related to one another. It had its inception in a paper originally prepared for the AIEE 1952 Southwestern District Meeting and in subsequent discussions which the author had with interested engineers in the utility industry. It has been prepared in its present form at the request of the editors of COMBUSTION.

By ARNOLD RICH
Consulting Engineer, Fort Worth, Texas

SUITABLE provisions for the various types of outages encountered in electric-system operations are major factors controlling the aggregate reserve supply necessary which, in turn, is a most important part of the total system capacity required. As provision for outages is a critical feature of system-operating and capacity-extension programs, it is evident that any means that will facilitate planning for outages is needed. One such need could be met by a classification of outages similar to the uniform terminologies now in common use in other areas of power-system engineering. Such a classification would have the advantages common to others, e.g., it would greatly facilitate the preparation and use of operating and planning programs; exchange of information between interconnected companies; evaluations of the effectiveness of preventative-maintenance practices; the suitability of plant-layout features; etc.

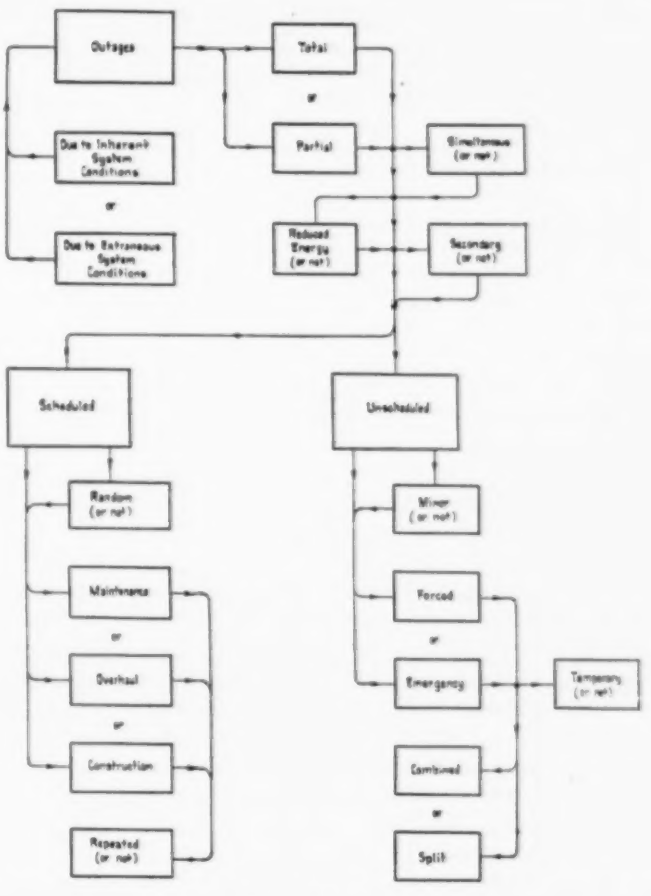
The need for such a common terminology is clearly evidenced by the many different terms now used to describe outage types. Quite frequently, several terms have been applied to the same outage type and the distinctions made between types have by no means been clear. Such lack of uniformity in nonmenclature, which also applies to discussions of other system planning and operation features, results in some confusion and restricts progress in solution of capacity-vs.-load problems.

To provide a basis for the considerable discussion required for the preparation of a uniform outage-classification, the writer presented an AIEE paper in which he attempted to chase the general problem out into the open, where all aspects can be clearly viewed and discussed. This article is based not only on the above paper, but also on the able and rather numerous discussions of it received so far, which indicate a widespread interest.

This is a universal classification applicable not only to the generating facilities alone, but to all other parts of an aggregate system. It is not based on the use of different terms, as governed by the facilities involved, for the same outage type. Instead, all terms apply to outages of all facilities, i.e., outages are classified by types according to the associated conditions, such as, the purpose of an outage, its effects on the system power supply and operation of other facilities, the amount of advance notice and reserve supply available, etc. For example, a shutdown scheduled for overhaul work is a scheduled overhaul outage regardless of whether the equipment removed from service is a boiler, a steam or hydraulic turbine, or a synchronous condenser. Likewise, a scheduled shutdown for construction purposes of either a boiler and turbine, or a tie line, is a scheduled construction outage.

Outages are primarily defined in the following classification as single events. Multiple outages as such are not included. However, the secondary and simultaneous outages listed are typical of multiple-outage types. Cyclic reductions in the capabilities of facilities, e.g., those due to seasonal circulating-water or ambient temperature increases, are considered as system-capacity reductions without an associated outage.

Any study of outages involves some consideration of the system reserve requirements as created by the outages and of the reserve supplies needed to provide for the



Outage classification chart showing relations between outage types

outages. In this discussion, the following general terms are used to cover the system reserve-supply sources usually encountered. Surplus capacity is that released by the normal (and unusual) load cycles; e.g., the daily, weekly, monthly and seasonal cycles. To this can be added capacity released by customer load-control arrangements, such as those included in some service contracts. Spare capacity is that available when needed regardless of the load cycles, such as spare capacity in steam-station auxiliary equipment, spare boiler or turbine capacity, etc. The aggregate supply for scheduled outages is furnished by the surplus capacity on hand at the time, plus any spare capacity available for this service. Reserve for unscheduled outages, and system-control service, is the unloaded generation connected to the system and ready to pick up or drop load upon response to throttle or gate operation, as allowed by the operating characteristics of facilities. At any time, the total reserve supply consists of that available for scheduled outages, plus the reserve provided for unscheduled outages and control service. Reserve itself is defined as the difference between the capacity available to a system and its load demand, all at the time (and place) under consideration.

Definitions of Types of Outages in Electric-Power Systems

A. OUTAGE—An outage is an event, necessitated by adverse conditions involved in the operation of power-supply facilities, that curtails the system capacity available for service.

1. TOTAL OUTAGES are those resulting in a loss of all of the capabilities of power-supply facilities.
2. PARTIAL OUTAGES are those resulting in a material reduction in the capabilities of power-supply facilities.

B. SCHEDULED OUTAGES are those shown on any list required for the performance and coordination of system maintenance and inspection operations; e.g., maintenance-outage schedules and maintenance-force work plans.

1. MAINTENANCE OUTAGES are the scheduled outages, of limited duration, required for miscellaneous minor routine, or other maintenance, repairs, and inspections.
2. OVERHAUL OUTAGES are the scheduled periodical lengthy shutdowns required for major inspection and overhaul purposes.
3. CONSTRUCTION OUTAGES are the scheduled shutdowns required for construction operations not connected with the repair of facilities.
4. RANDOM OUTAGES are those not necessarily listed on the system maintenance-outage schedule, due to the time during which sufficient reserve will be continuously available, where required.

C. UNSCHEDULED OUTAGES are those that either occur at once, or that must be made in a very short time, so that they cannot be effectively coordinated in the system maintenance plans.

1. FORCED OUTAGES are the unscheduled outages that happen at once, or that must be made immediately.
2. EMERGENCY OUTAGES are the unscheduled outages for which a short time delay is allowable before the outage must be made, forthwith.
3. MINOR OUTAGES are those that occur when a reserve-supply surplus is available, that approximates the capacity lost.
4. TEMPORARY OUTAGES are those that can be readily eliminated by restoring the associated facilities to service shortly or immediately after the outage occurs.

D. SPECIAL OUTAGES are those that require some special consideration before their complete classification can be definitely determined.

1. COMBINED OR SPLIT OUTAGES are the ones, initially occurring as unscheduled outages, during which previously scheduled work is done. With no material duration extensions for such work, they are considered as Combined Unscheduled Outages. Otherwise, they are considered as Split Outages, with the outage duration split between the scheduled and unscheduled categories accordingly.
2. SECONDARY OUTAGES are those that are the indirect result of previous outages of accessory and associated equipment and facilities.
3. REPEATED OUTAGES are the successively scheduled outages all made for the same general purpose.
4. SIMULTANEOUS OUTAGES are those that occur, or are made, at practically the same time.
5. REDUCED-ENERGY OUTAGES are those that curtail the production of usable energy, without a corresponding reduction in the total available capacity needed at the time.
6. EXTENDED LONG-TIME OUTAGES are those resulting in system power-supply reductions prolonged to such an extent that consideration must be given to treating the situation as the development of a permanent power-supply deficiency, requiring material system improvements for its elimination.

Discussion

This discussion covers the specific definitions listed above.

A. OUTAGES—The term "Outage" is a general one that covers the occurrence of all shutdowns and reduced-capacity operations, of facilities in commercial service, that are made because of adverse operating conditions, without regard to their time of occurrence or the need, at the time, for service from the facilities involved. Therefore, an outage is an event and not a condition. Shutdowns due solely to a lack of need for service from the associated facilities are not included. This term covers effective output reductions due to adverse conditions inherent of, and those extraneous to, the system as described below.

Examples typical of inherent system conditions would be total or partial output reductions due to boiler or mill outages, blading trouble, failure of transmission facilities, and outages for inspection and maintenance. The completion of work and arrangements needed to restore the facilities to full service when required would be under the control of the system involved, to a large extent at least.

Those typical of conditions extraneous to the system would be capability reductions due to poor grades of fuel or insufficient fuel supplies, adverse stream-flow conditions, etc. The application, by the system, of expedients to eliminate such outside or foreign troubles and so restore the facilities to full service would, in most cases, be at least very difficult and often impossible.

1. TOTAL OUTAGE. As listed above, this term covers those shutdowns that result in a loss of the entire load-carrying capabilities of facilities.

2. PARTIAL OUTAGE. This term covers outages that require the operation of facilities at a materially reduced capacity. They are often made in anticipation of trouble and, in some cases, follow total outages after provisions are made for temporary operation under the new conditions.

Typical examples are boiler-output reductions due to fan outages, low gas-fuel pressure, reduced feed-pump capacity, and the loss of one regenerative-type air heater. Others are reduced machine outputs due to boiler outages, reduced circulating-water-pump capacity, loss of hydrogen pressure, fouled condensers and intake screens, the removal of damaged blading, etc.

B. SCHEDULED OUTAGES—This term covers the outages that can be anticipated so that maximum advantage can be taken of any opportunities that may exist to replace the associated generation loss with suitable alternative capacity. The advance notice available is the primary consideration. If, due to this notice, possibilities for limiting the associated reduction in needed power supply can be determined, the outage can be placed in this category. The degree to which this reduction can actually be limited should not govern, as it varies from no effective amount to amounts meeting all requirements due, primarily, to factors beyond effective control by the system at the time. Likewise, the extent to which a needed outage requires changes in previously prepared plans should not govern, as some deviations from most advance arrangements are common and cannot be avoided.

In order to avoid adverse reductions in the total capacity required, many outages must be included in the system maintenance-outage schedule, i.e., the plan for coordinating the variable reserve supplies with releases of facilities for needed work. Typical examples are the shutdowns that can be made when the seasonal and other load cycles result in a suitable supply of surplus capacity. In these cases, the outage duration (short or long-time) and the capacity amounts involved are such that the event can be timed to occur when the reserve capacity available will be suitable for the needs.

Some outages cannot be so arranged and must be made when an insufficient amount of alternative capacity exists. These unavoidable outages are often due to numerous machines to be scheduled during the year, together with a lack of surplus capacity and spare facilities. In these cases, the first expedient usually applied is the use of the reserve normally provided for unscheduled outages.

As a rule, some system reserve supply is continuously available in satisfactory amounts and locations, e.g., that part furnished by spare capacity and facilities such as transformer units, circulating-water-pump and boiler capacity, and unused surplus generation on hand for adequate periods. Under these conditions, some outages can be made almost at will at any time and others can be made when convenient during rather lengthy periods, all without adverse effects on required capacity or service continuity. Typical examples would be outages required by the unforeseen development of a need that could be delayed for a suitable period, as contrasted with unscheduled outages, and routine maintenance outages of certain facilities in suitable locations. In all such cases, however, the necessary plans can be made, regardless of their extent or the parts of the system organization involved.

Outages that can be made when convenient, either at any time or during certain suitable periods, need to be included only in the work schedule of the maintenance forces for completing all anticipated inspection and repair operations. Inclusion in the system maintenance-outage schedule is not necessary as adverse effects on needed capacity and service continuity are not involved. Such outages might be considered as random scheduled outages, since they can be planned in a more or less casual manner, at least as far as the system daily operating routine is concerned, although they may have material effects on the maintenance-force-work schedule. The needs of the maintenance-outage schedule are controlling, however, as the maintenance-force-work schedule can be arranged, under normal conditions, to take maximum advantage of all opportunities to complete needed work as limited by economic factors.

Most scheduled outages are made for maintenance, repair and inspection purposes, as covered by the following two maintenance and overhaul categories. However, in some cases shutdowns are required for construction purposes, as covered by the third category. The fourth type covers the casual or random shutdowns.

1. MAINTENANCE OUTAGE. This term covers the routine, and other, scheduled outages needed to provide for repair and for repetitive maintenance work, all limited in extent and duration and made to improve operation and reduce the lengthy shutdowns required for major overhaul purposes.

Typical examples are the outages made for condenser, boiler and insulator cleaning, turbine washing, adjustments like governor speed-droop changes, and repair and replacement of certain parts. In many cases, the surplus capacity released by the daily or weekly load cycles will suffice for a reserve supply for these short-time shutdowns.

2. OVERHAUL OUTAGE. This term covers the scheduled periodical lengthy shutdowns required for major overhaul purposes. Typical examples are those made for a turbine opening for complete inspection and overhaul, hydro unit dismantling for major overhaul and realignment, and others. As a rule, for these long-time shutdowns, surplus capacity released by the seasonal load cycles furnishes the reserve supply needed, together with any spare capacity on hand.

An important difference between these lengthy outages and the above maintenance outages of limited duration is the outage time involved. As conditions vary greatly, both on and between systems, no general rule can be followed for definitely defining the two categories. Therefore, the controlling factors are those that apply for particular systems.

3. CONSTRUCTION OUTAGE. This term covers the scheduled non-routine outages required to allow the completion of system (and other) construction operations not connected with the repair of facilities. In some cases, the maintenance and overhaul requirements of the facilities involved can be scheduled to coincide with the need for these outages. In these cases, the resulting outage is

usually placed in the scheduled maintenance or overhaul category. In many cases, however, the outage must be made and scheduled solely for construction purposes and is, therefore, placed in the construction category. Typical examples would be line shutdowns for relocation purposes only, and those other construction shutdowns with which no other work could be coordinated.

4. RANDOM OUTAGES are those included in the maintenance-force-work schedules, like all other scheduled outages, but omitted from the system maintenance-outage schedules due to the time during which sufficient reserve will be continuously available, where required.

C. UNSCHEDULED OUTAGES—This term covers those unforeseen non-routine outages for which no effective advance notice is available because of the sudden development of a critical need, or cause. As a result, they either are not or cannot be delayed until changes in existing schedules can be made for the replacement of the generation involved. Therefore, the system reserve on hand for unscheduled outages must be used accordingly.

Unscheduled outages occur or are made, as a rule, to reduce interruptions to service and damage to equipment and facilities. Included are those immediate outages that occur due to automatic and manual removals of facilities from service, for due cause, together with those occurring because of faulty manual operation of facilities, such as switching errors. Also covered are those for which a short time delay is allowable before the outage must be made. However, this permissible delay is not sufficient to allow the outage to be coordinated with the system maintenance schedule so that the alternative capacity ordinarily used for scheduled outages can be applied. In addition, more or less minor outages that do not require the use, as replacement capacity, of the reserve normally provided for this outage type are included, together with the temporary outages that can be easily and quickly eliminated.

The following four categories are based on the above associated condition, which determine the manner in which the outages ordinarily encountered should be classified.

1. FORCED OUTAGE. This term covers those output reductions resulting from the removal of facilities from service with the minimum possible delay. Typical examples are the immediate outages that occur due to protective-relay operation (including hydro-generator unloadings made regardless of turbine overspeeds), and those made as soon as possible because of turbine-blading troubles, loss of vacuum or feedwater, failures of boiler pressure parts, etc.

2. EMERGENCY OUTAGE. This term covers those outages that can be slightly delayed, due to controlling factors existing at the time. In these cases, the results of the conditions causing the need for the outage are such that they can be tolerated for a short period before the outage must be made, often without any further adverse effects. Typical examples are the conditions caused by increased turbine back-pressures, reduced steam pressures, loss of head due to floods, loss of feedwater storage, and delayed hydro-unit shutdowns that can be made to avoid turbine overspeeds.

3. MINOR OUTAGES are the relatively unimportant ones, from a power-supply standpoint only, that occur when a reserve-supply surplus is available that approximates the capacity lost. Under such conditions, and as far as needed capacity is concerned, such an event would cause little concern as it would not materially reduce the amount of reserve needed. Such a surplus of reserve often exists for various periods, during normal operation, and equipment shutdowns occurring under the above conditions are not isolated. As far as system operation is concerned, such outages can be considered as having minor characteristics, because of their unimportant or insignificant effects on the overall system power supply necessary at the time.

4. TEMPORARY OUTAGES. The outages covered by this term are the ones that can be quickly eliminated in a positive manner. In these cases, the facilities involved can be restored to service by manual or automatic means without repair work. A typical example is a line outage caused by a temporary fault. Another is a turbine shutdown made because of a loss of vacuum due to the drop out of a starter on a circulating-water-pump motor.

These outages can be eliminated, in the first case, by reclosing tripped breakers only and, in the second case, by restarting the circulating-water pump and the associated turbine. In both cases, the interruptions in service from the facilities involved are short-time only. Little or no repair work is required at the time, obviously, although some later repairs and adjustments may be necessary.

D. SPECIAL OUTAGES—Some outages are more common than others and most outages can be readily placed in the two major classifications described above, either prior to the time they are made or shortly after they happen. On the other hand, certain outages must be considered as special due to the associated exceptional conditions, e.g., those that cannot be finally classified when they occur, the ones that are not often encountered in the general run of system operations, etc. This special-outage category is illustrated by the following typical examples.

1. COMBINED OR SPLIT OUTAGES. These outages are those that involve: (*a*) no advance notice, and (*b*) an actual duration sufficient to allow the performance of planned work previously reserved for scheduled-outage periods. Obviously such outages are initially classified as unscheduled. If the duration is not extended to cover previously scheduled work, the outage remains as unscheduled and is considered to be a combined unscheduled outage. Otherwise, consideration must be given to placing the outage in the scheduled class, as advantage has been taken of opportunities to previously plan certain needed work.

If the outage duration is so extended, the amount of the extension made determines whether it should be finally listed as scheduled or unscheduled, or divided between the two classifications and considered as a split outage. As conditions vary greatly, no definite rule can be followed in such cases. The controlling factors are those that apply for specific systems at the times involved.

2. SECONDARY OUTAGES. These outages are the ones that are the indirect result of any outages of associated equipment or facilities. Typical examples would be those caused by outages of essential accessory equipment, such as, a turbine shutdown due to loss of excitation or vacuum or troubles in the accessory electric equipment, and boiler shutdowns due to feedwater-sup-

ply failures or troubles in the fuel-handling system. Others included are those caused by closely associated (but not accessory) equipment such as turbine outages due to boiler trouble or maintenance.

Such outages can be scheduled or unscheduled. As a rule, however, they are unscheduled as maintenance plans are arranged for simultaneous work on associated equipment, as much as possible, to obtain maximum use of the system surplus and spare capacity.

These outages result in multiple output reductions consisting of both the initial primary outage and the resulting subsequent secondary outage. One may be partial and the other total, e.g., the loss of one boiler in a two-boiler layout resulting in a total primary boiler outage and a partial secondary turbine outage.

3. REPEATED OUTAGES. In some cases, due to favorable conditions, several consecutive or repeated scheduled outages for the same purpose can be arranged to provide for the completion of repair or maintenance, thereby reducing at suitable times the aggregate demands on the system reserve supply for scheduled work. In these cases, each instance is considered as a separate outage regardless of the interval between them, although a common need or cause applies to each outage. Included are the shutdowns for repairs when the work can be stopped on notice and the facilities replaced in service, without delay due to the work involved.

4. SIMULTANEOUS OUTAGES can be both scheduled and unscheduled. For unscheduled outages in particular, this term should be restricted to multiple outages that occur at the same time, i.e., those that are really simultaneous. It has been applied, in certain cases, to subsequent outages that have occurred before previous ones had been eliminated, almost regardless of the time interval between them. This qualification was based, apparently, on the fact that the subsequent outages happened before the previous ones could be eliminated. Such conditions do not place multiple outages in this category, as the length of time between their occurrence is best criterion.

The question naturally arises as to the interval actually covered by the same-time restriction. Obviously, the coverage includes multiple outages occurring at the same instant. For all practical purposes, however, it also includes those with a short-time interval between them, e.g., a number of cycles (if and when such short times can be determined or estimated) or, in some cases, a few seconds. It is apparent that no general rule can be applied to specify the maximum actual time intervals between such unscheduled outages that will not remove them from this category. Operating conditions and general conceptions associated with particular systems will govern this specification.

Outages of the above described Secondary type may or may not be simultaneous outages, in addition. This depends upon whether the actual period between the primary and secondary outages involved in such an occurrence is within the time-interval limit in use.

5. REDUCED-ENERGY OUTAGES. Important markets for the energy that can be generated by surplus and spare capacity are not unusual. Typical examples of such loads are the off-peak demands of pumped-storage hydro plants, and certain industrial water-heating loads. Similar examples of such energy sources are steam-electric capacity released by the load cycles, and surplus hydro capacity available during periods of above normal stream flow.

Outages of such capacity result in a loss of usable energy production, without a corresponding reduction in the system capacity required, at the time, for load-carrying and reserve service. Outages of this type are unscheduled, as a rule. They differ from the minor unscheduled outages previously defined, primarily because of the associated loss of a kilowatt-hour supply and the revenue that would have been earned at the time.

6. EXTENDED (LONG-TIME) OUTAGES. Certain power-supply reductions materialize that cover very extended periods until corrective measures can be applied to eliminate the trouble. In these cases, the problem is to decide whether the reduction should be considered as an exceptional outage, or as a power-supply deficiency, caused by contingencies beyond control by the system, that should be provided for in the system capacity-extension program.

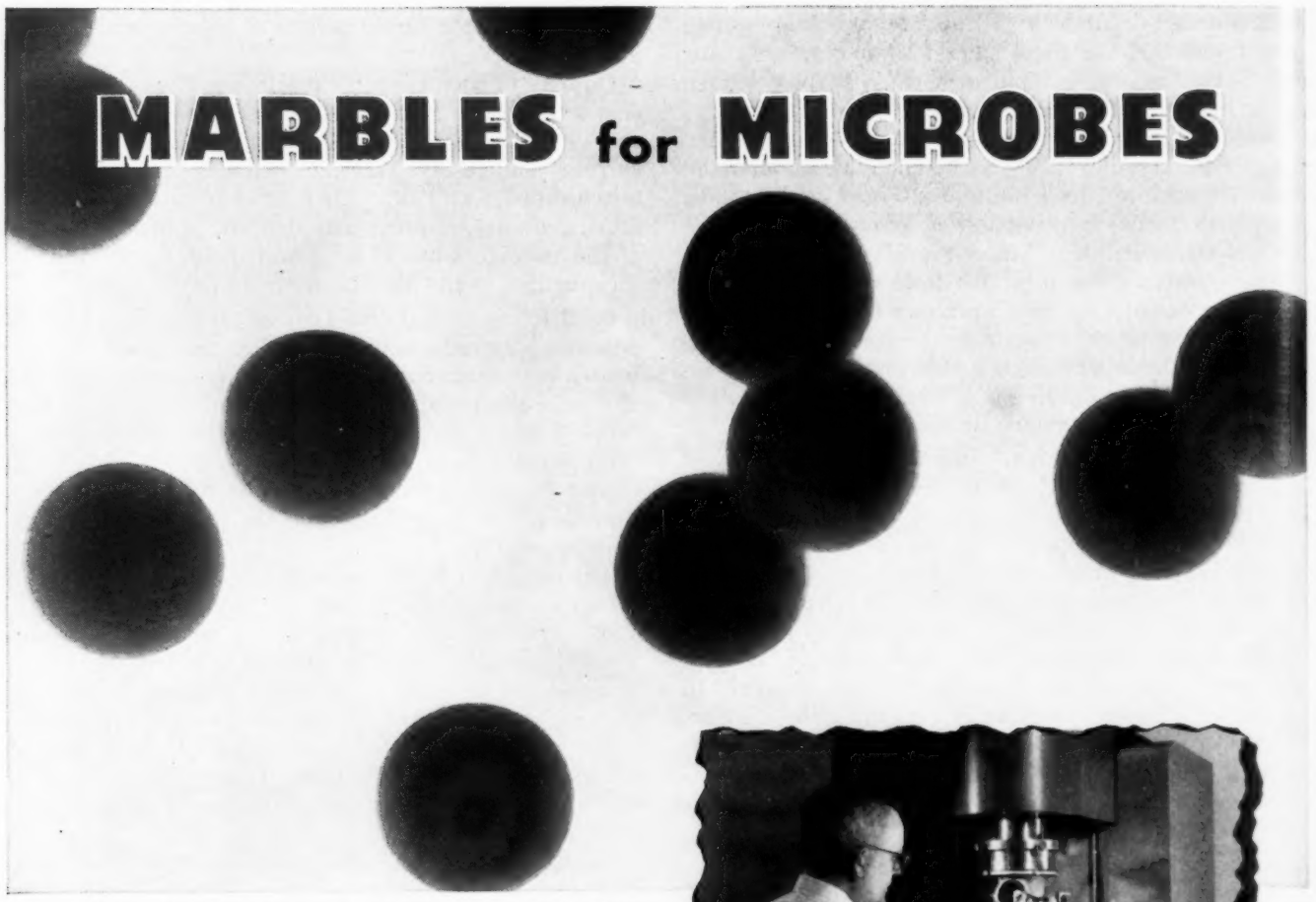
The reduction can be considered as an outage if its effects can, and probably will, be eliminated in time to avoid unreasonably adverse power-supply conditions. Typical examples would be shutdowns caused by failures or accidents resulting in extensive damage to facilities that could be repaired in time, or power-supply reductions due to uncontrollable extraneous factors, such as adverse stream-flow conditions caused by a series of floods, reoccurring gas-fuel curtailments during cold-weather periods, and others.

On the other hand, when material system additions must be made to avoid consequent adverse effects on the total system power supply, the reduction should not be considered as an outage with, maybe, special features, but as a power-supply deficiency that has not been provided for in the system-development plan. Examples of such conditions, typical of extraneous factors, would be continuing excessive fuel curtailments with no relief in sight, and unanticipated stream-flow deficiencies that might be expected to reoccur. Other examples, typical of inherent conditions, are the development of those effective plant-output bottlenecks, the elimination of which cannot be reasonably anticipated without system improvements.

7. OTHER SPECIAL-OUTAGE TYPES. Under certain conditions, other special-outage types will occur or will be required for one reason or another. Typical examples are: (*a*) outages that result in customer-service interruptions only; (*b*) those that result in any loss of load; (*c*) outage types for use in comparing the performances of various makes and types of equipment; (*d*) others for use in evaluating the effectiveness of preventative-maintenance practices; (*e*) plant shutdowns or output reductions due to extraneous factors, instead of trouble or work in the station, and (*f*) outages that are in between the definite scheduled and unscheduled types, due to the advance notice and allowable scheduling involved.

Because of the many different circumstances that can and do exist, a comprehensive special-outage list for general use is not practical. Operating conditions encountered, together with the scope and general purpose of the outage classification used, will determine the special-outage lists needed for particular systems. Obviously, in many cases, these outage types will be more or less common, instead of special, from the standpoint of the system involved.

MARBLES for MICROBES



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ELECTROSTATIC PRECIPITATORS

By H. J. WHITE

Research Corporation

The following is abridged from a more extensive paper presented at the 1953 AIEE Winter General Meeting in New York. It outlines the principles of an electrostatic precipitator, discusses the composition and characteristics of fly ash, reviews precipitation design and touches upon combination mechanical and electrostatic collectors.

Application of electrostatic precipitation to the fly-ash removal problem is almost as old as the use of pulverized coal in the power-generation field. The first pulverized-coal-fired power boiler in America was installed in 1919, while the first electrostatic precipitator applied to the collection of fly ash went into service only four years later. Since then electrical precipitation has become established as a standard and effective means of dealing with the fly-ash problem as witnessed by the fact that more than 500 installations have now been made in this country.

The extent of the fly-ash problem is strikingly shown by figures on pulverized coal burned by the utilities which in 1948 amounted to over 65,000,000 tons. The corresponding fly-ash quantity that could be emitted would be about 6,000,000 tons annually, assuming an average ash content of about ten per cent. The general problem of fly-ash emission may be further illustrated by considering a large modern boiler producing, for example, 1,000,000 lb of steam per hour. Such a boiler will exhaust flue gas at the rate of about 500,000 cfm at a temperature of about 300 F. Using a typical average figure for fly-ash concentration of 2 grains per cubic foot, the dust emitted from the furnace will amount to about 140 lb per min, or 100 tons per day. In order to deal effectively with this problem, collecting equipment must be provided to continuously clean 500,000 cfm of hot flue gas with an efficiency of 90 per cent or over, and with ash-disposal arrangements for some 100 tons per day.

Many cities now have ordinances to regulate smoke and dust conditions, and the ASME has prepared example sections for smoke regulation ordinances, looking toward realistic and economically possible control. In general terms, the ASME Code states a maximum figure for dust emission of 0.85 lb per 1000 lb of gas (equivalent to about 0.3 grain per cu ft at 300 F), adjusted to 50 per cent excess air, and a maximum required collector efficiency of 85 per cent. Utilities have provided collection equipment giving performances well above these standards. Specified efficiencies of new equipment have climbed steadily, with many present-day precipitator installations providing efficiencies as high as 98 per cent.

Operating Principles

In an electrostatic precipitator, gas containing particles in suspension is passed between highly charged electrodes. Electric forces act on individual particles and cause them to be collected on the electrode surfaces. The rate of particle collection and the effectiveness of the process increase in direct proportion to the strength of these electric or Coulomb forces. Basically, such a precipitator must provide two essential functions: first, the suspended particles must be given an electric charge, and second they must be subjected to a strong electric field to insure their effective removal from the gas stream.

In practice, electric charging of the particles is accomplished by means of ions produced in the d-c corona discharge. The collection of the charged particles may also be effected by the corona field, in which case the precipitator is known as a single-stage, or Cottrell precipitator. Or the collection may be effected by passing the charged particles between condenser plates with no corona discharge present. In the latter case the precipitator is described as a two-stage type because the charging and collection are carried out in two separate stages. The Cottrell type precipitator has proved superior for industrial gas cleaning. The two-stage type is used primarily for air-cleaning applications where the amounts of ozone and oxides of nitrogen which are unavoidably produced in the corona discharge must be held to very low values.

Fly Ash and Furnace Gas Characteristics

Both the basic and practical precipitator design factors for any given application are determined primarily by the properties of the gas and of the dust to be treated in the precipitators. Thus, the corona and sparking characteristics which determine the maximum fields are functions of the dielectric properties of the gas and of the resistivity properties of the dust, while the gas viscosity and the particle size of the dust are inherent physical properties of the gas and dust respectively.

Furnace Gases

The furnace gases comprise the original nitrogen and water vapor contained in the air plus the products of combustion, chiefly CO_2 and water vapor. Typical composition ranges, as determined after the air preheater are:

	Per Cent
N_2	77
O_2	4 to 5
CO_2	12 to 15
H_2O	4 to 10

In addition, there are small quantities of SO_2, of the order of 0.1 per cent, and of SO_3, of the order of 0.001 per cent.

The flue-gas temperature at the precipitator inlet ranges between about 250 and 450 F, with 300 to 350 F being the most common range. Moisture content and dewpoint of the gas depend primarily on the volatile in the coal. However, it is important that trace quantities of SO_3 present in the gas tend to raise the dewpoint by appreciable amounts. The presence of SO_3 also influences the electrical resistivity of the ash. In precipitator operation it is essential that temperatures be maintained considerably above the dewpoint to avoid corrosion difficulties.

Corona and electrical operating characteristics are strongly influenced by the flue-gas properties, particularly by the amounts of water vapor, CO_2 and SO_3 present. Since the amounts of these gases produced in the furnace vary considerably with the type of coal and with furnace operating conditions, it is not surprising that the electrical characteristics of precipitators also vary widely from job to job.

The amount of combustion gas produced in a furnace is approximately 12 to 15 lb per pound of coal burned, or, in relation to the amount of steam, about 1.35 lb of combustion gas per pound of steam generated. Thus, for a large boiler producing 1,000,000 lb of steam per hour the combustion gas would be 22,500 lb per min, or about 420,000 cfm at 300 F. Air inleakage through the air preheater, gas flues or furnace walls may materially increase the amount of gas reaching the precipitator.

Composition of Fly Ash

Fly ash originates from the inert, inorganic, residue from the pulverized coal particles together with varying amounts of carbon or coke present as the result of incomplete combustion. In general, the inorganic or true ash-particles are comprised primarily of silicates, oxides and sulfates, together with small quantities of phosphates and many other compounds present in trace quantities.

The Bureau of Mines lists 21 metals present in ashes from American coals, ranging from arsenic to zirconium.

More than about 10 per cent of carbon in the fly ash may be disadvantageous from the standpoint of electrical precipitation. The difficulty is not due to the carbon itself, but to the drifting nature of the relatively large porous coke particles with which the carbon is associated. Excessive carbon is also a disadvantage in the utilization of fly ash, particularly where it is to be used as a pozzolan in cement replacement.

Particle Size and Shape

Observations on fly ash made by means of optical and electron microscopes show particles present from below 0.01 micron diameter to over 100 microns. Particle shape is heterogenous and variable. Microscopic examination shows the presence of small, hollow, and frequently transparent or translucent spheres; broken fragments of these spheres; flakes; opaque, irregular particles ranging from pink to brown and black; fused agglomerations of small particles; and large irregular porous and partially burned gritty particles.

Specific gravity of fly ash varies not only from sample to sample but also for different particles of the same sample. Values of average density, as determined by a pycnometer method, usually lie between 2.0 and 2.7, although these figures do not include the extreme range possible.

The translucent, hollow spheres, which are characteristically present in most fly ash, usually range in size from below one micron up to about 44 microns. The irregular-shaped carbon particles generally range from 10 to over 300 microns. These vary in shape from slivers to highly irregular sponge and lace-like material and are commonly referred to as grit. The effective density of grit particles is relatively low, or only about one-third that of the fly ash as a whole. The low density and large size of the grit particles accounts for the difficulty sometimes encountered in retaining them in precipitators. However, it is important to note that this drifting tendency of the gritty particles results from physical characteristics of the particles themselves and is not fundamental to the precipitator, as has sometimes been asserted.

Electrical Resistivity

In the operation of a precipitator the suspended ash particles are driven to the collecting electrode surfaces where they build up to form layers usually from $^1/_8$ to $^1/_2$ in. thick. The corona current from the high-tension wires must pass through these layers to reach the grounded collecting plates as illustrated in Fig. 1. Thus a certain voltage will be built up across the collected dust layer in accordance with Ohm's Law.

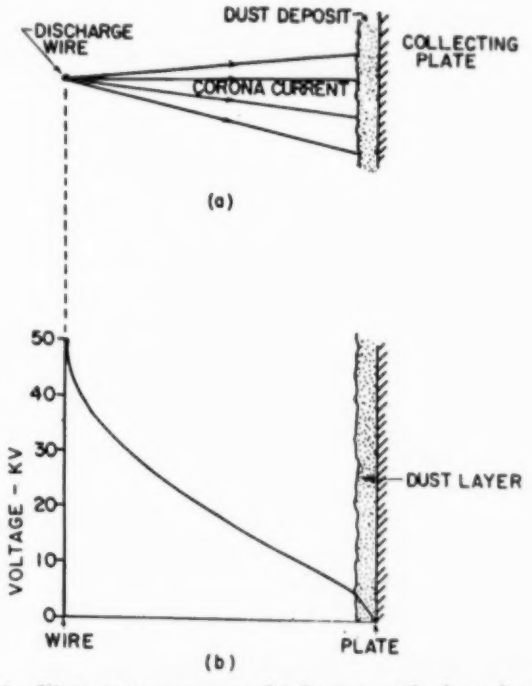

Fig. 1—Illustrating corona discharge with dust layer on collecting plate—(a) is pictorial sketch and (b) potential distribution

Theory, experiment and field experience all indicate that when the dust resistivity exceeds a critical maximum value of about 2×10^{10} ohm-cm, the precipitator operation will tend to become subnormal due to the onset of intensified sparking caused by the high resistance ash on the collecting surfaces. This critical value of resistivity is not sharp but rather is representative of a diffused or penumbral region in which precipitator sparking increases and performance tends to fall off.

Chemical compounds which in small quantities greatly reduce dust resistivity are designated "conditioning

agents" and have long been used in electrical precipitation. Such compounds are specific for each type of dust. Research has disclosed the effectiveness of SO_3 for fly-ash conditioning. It appears that the traces of SO_3 naturally present in boiler gases are adequate in most cases to maintain the bulk resistivity of the ash below the critical value of 2×10^{10} ohm-cm. The troublesome higher resistivity ashes occasionally encountered are the result of unusually low natural SO_3 content. Artificial addition of SO_3 in operating installations has substantiated laboratory findings on this point in that it is possible to greatly reduce sparking and substantially increase efficiency by the addition of very small percentages of SO_3 to the flue gas ahead of the precipitator.

Research has indicated further that the electrical conductivity of fly-ash particles is closely associated with the adsorption of SO_3 on the particle surfaces. This adsorbed SO_3 is present as water-soluble sulfates, usually of the alkali earths, such as calcium, sodium and potassium. It is occasionally found that with ashes containing very low sulfates the conditioning effect is primarily determined by the carbon or combustible content of the ash. These cases are rare, however.

Precipitator Design

Precipitator design is broadly determined by two factors: first, the total effective area of the collecting electrodes, which essentially determines the physical size of the precipitator; and second, the corona and sparking characteristics of the electrode system, which determine the amount and size of high-voltage rectifier equipment required. In addition to specified values of precipitator cleaning efficiency and gas current to be treated, the following operating factors must be considered:

a. Temperature, pressure and dewpoint of gas,
b. Type of coal and amount of ash,
c. Type of furnace and furnace operating conditions,
d. Maximum permissible draft loss and possibility of overload gas flow conditions,
e. Available installation space.

One of the most important requirements of precipitator design is that of reliability.

Mechanical Design

Electrostatic precipitators are usually large compared to other power auxiliaries and frequently more space is required than can be conveniently allocated. The resulting tendency to compromise on size sometimes has led to unfavorable operating experience, particularly in those cases where the boiler and precipitator continuously operate well above design capacity.

Although most precipitator installations have been located on the roofs of power houses, the recent trend has been toward ground-level locations, either indoors or outdoors. Except for outdoor ground-level locations, few arrangements lend themselves to later precipitator expansion which may become necessary because of increased gas volume or the need for improved collection efficiency.

Fly-ash precipitators generally are of the duct-type with horizontal gas flow. Duct width is a compromise between providing the largest possible number of collecting plates in a shell and ability to maintain adequate electrode ridigity and dust build-up space. A duct width of 8 in. has been most commonly used, and appears to represent the best compromise.

The basic precipitator shell dimensions are determined by the maximum permissible gas velocity in the precipitation zones and by the total collecting electrode area necessary to obtain the required cleaning efficiency. In practice, the practical dimensions for the active precipitation zones in fly-ash precipitators have been 15 to 20 ft in height and 12 to 24 ft in length in the direction of the gas flow. The most usual location is between the outlet of the air preheater and the inlet of the induced-draft

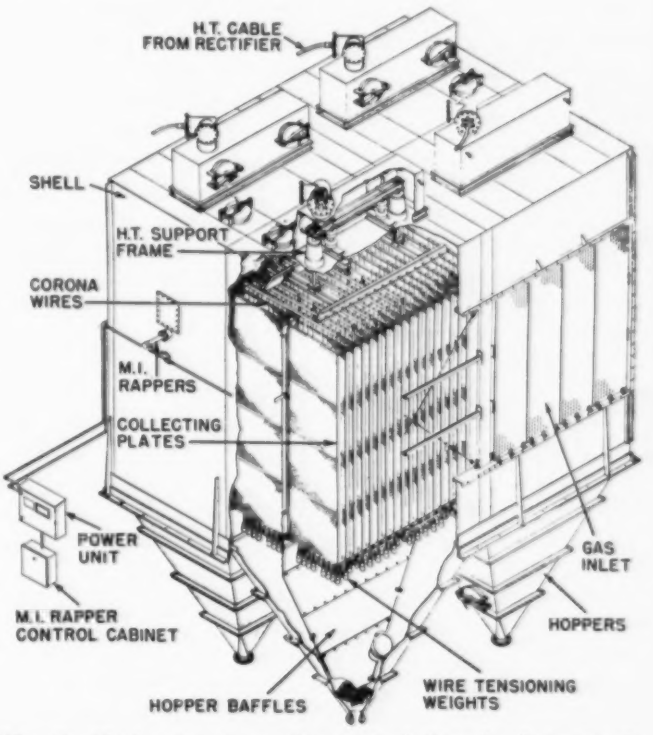

Fig. 2.—Basic structure of a typical fly-ash electrostatic precipitator

fan, although there are some installations in which the precipitator is placed immediately after the induced-draft fan.

The basic precipitator structure is illustrated in Fig. 2 in which the essential parts are the high-tension frame and corona wires, the collecting plates, the enclosing shell and supporting frame, the hoppers and the electrode rappers.

Electrodes

The corona discharge electrodes are usually round steel wires of about 0.1 in. diameter, or equivalent twisted-square wires, hung in the ducts about 6 in. apart. The discharge wire support frame is suspended from porcelain insulators mounted in suitable housings on top of the precipitator shell. Tile bushings are used to seal the insulator compartments from the dust and gas stream, so that only infrequent insulator cleaning is required. Electrical connections to the high-voltage rectifiers may be made by high-tension cables, or the rectifiers may be mounted on, or adjacent to, the precipitator itself, without the use of cables.

Collecting electrodes have taken various forms, such as concrete plates, perforated or expanded metal plates, V-

plates, rod curtains, and various hollow electrodes with pocket arrangements on the outside surface for conducting the precipitated dust to the hoppers in quiescent gas zones. Concrete-plate collecting electrodes were used in the early type of fly-ash precipitators, but were abandoned in 1937 because of excessive costs and weights relative to fabricated metal electrodes. Smooth plates usually are not suitable for fly-ash collecting because of the tendency of the gas stream to re-entrain the collected ash from the unprotected plate surfaces. The perforated- or expanded-metal plates provide a multiplicity of close-spaced holes which hold the ash, while the end baffles on the plates shield the perforated surfaces from the direct scouring action of the gas. The V, or chevron plate, is comprised of V-shaped vertical members which form a series of shielded-pocket spaces between the electrodes for collection and retention of the ash.

The hollow, or pocket-type electrodes are attractive in principle but in practice it has been found that a large proportion of the dust actually falls on the outside of the plates. Also much of the dust collected in the upper openings actually escapes to the outside through the lower openings because of the piston action of the falling dust. Another disadvantage of these plates is that they occupy more space.

Gas Flow

Gas flow in precipitators is always turbulent. The smooth, laminar flow characteristic of viscous fluids, such as oils, is seldom encountered with gases. Although turbulent gas flow may be regarded as detrimental, it is inherent and unavoidable and the best that can be done is to keep the degree of turbulence as low as possible.

Fly-ash precipitator gas flow problems usually start at the outlet of the air heater rather than at the inlet of the collector. It is not usually practical to adjust the gas flow pattern after the gases have entered the precipitator, so that means for providing the uniformity of gas distribution essential to optimum performance are normally provided in the flue connection between air heater and precipitator.

In general, the basic gas flow problem is to reduce the incoming gas velocity uniformly from the 25 to 50 fps normally existing in the flue to the 5 to 10 fps required in the precipitator, and to accomplish this with a minimum of turbulence and eddying. This involves expansion of the gas stream and transformation of the excess kinetic energy, preferably into potential energy, or if necessary into frictional loss.

Rappers

Deposits are usually dislodged by mechanically jarring or vibrating the electrodes, a process referred to as "rapping." In some fly-ash precipitator applications, particles tend to build up on the discharge electrodes as well as on the collecting electrodes, and this may occur to such an extent that the corona discharge is choked off and precipitation efficiency falls. In these cases it is necessary to provide effective rapping means for both the discharge and collecting electrodes. Far from being a minor adjunct in electrical precipitation, rapping is of the utmost importance in determining overall performance and has been one of the difficult problems. A satisfactory rapping system is characterized by a high degree of reliability, by ability to maintain uniform and closely controlled raps over long periods without attention and by flexible and easily controlled rapping intensity.

With the trend toward higher efficiencies and cleaner stacks, the clouding and puffs associated with intermittent rapping of electrodes have become increasingly objectionable, even though it may be demonstrated that the dust loss during rapping will reduce overall efficiency by only 2 or 3 per cent, or less. The psychological effect on the public of such clouding and puffs can scarcely be countered by technical arguments, and the only satisfactory solution is to eliminate them altogether. It is our conclusion, that continuous rapping of closely controlled intensity is the most satisfactory answer to the problem.

Most of the rapper systems of the past have been based on mechanical or pneumatic operating principles and suffered from certain inherent limitations and disadvantages, such as inflexibility and inability to stand up under field conditions involving moisture, dirt and corrosive atmosphere. Recently, however, there has been introduced a magnetic impulse rapper system based on electric and magnetic principles and free of many of the objections of earlier systems.

Electrical Energization

Successful precipitator performance depends basically upon establishing and maintaining the proper degree of electrical energization.

In large precipitators, the corona electrodes are always subdivided into several groups or sections and the individual sections separately energized from individual rectifier sets. This arrangement is necessary in order to avoid the deleterious effects of preicpitator sparking and of equipment outages, and to meet the uneven electrical conditions imposed by stratification of the gas stream which frequently occurs and which at present is usually unpredictable. The amount of electrode sectionalization used in any given case is a function of precipitator size and of rectifier equipment costs.

Industrial precipitator performance is superior when energized with pulsating rather than with direct voltages. This result has been confirmed by many years of experience, so that unfiltered rectified voltages are universally used in industrial precipitation practice.

Typical operating voltages for fly-ash precipitators of 8-in spacing range between 40 and 55 kv, with the higher values indicative of better adjustment and performance. Corona currents usually lie between 10 and 30 milliamperes per 1000 ft of discharge wire, while the average electrical power supplied to the corona commonly ranges between 40 and 120 watts per 1000 cfm of gas treated. In general, the higher voltages and powers will provide higher precipitator efficiency and performance.

High-Voltage Rectifier Sets

The general requirements for precipitation rectifier equipment are: adequate voltage and current capacity, high degree of reliability, ability to operate under heavy sparking conditions and long life and conservative ratings to permit operation under rather high ambient temperatures which frequently reach 50 or 60 C.

There is no evidence to indicate that the type of rectifier used has any significant influence upon the basic performance. Thus, synchronous-mechanical, electron-tube

and metallic rectifiers all provide substantially the same performance. Synchronous-mechanical rectifiers were used almost exclusively in the fly-ash field prior to 1945, and in spite of some obvious disadvantages have a record of reliable and satisfactory performance. Metallic rectifiers, although used to a considerable extent abroad, have as yet found only limited use in this country because of their relatively high initial cost. The present trend appears to be toward vacuum-tube rectifiers, which provide many advantages at reasonable costs.

Large fly-ash precipitators treating up to 500,000 cfm or more generally require at least three rectifier sets and may use as many as six or eight.

Recent research has shown that, contrary to earlier ideas, optimum collection efficiency for fly-ash precipitators is usually obtained with precipitator voltages set high enough to produce a substantial amount of sparking. The optimum degree of sparking depends upon many factors, such as precipitator size, ash concentration and ash resistivity, and in order of magnitude is frequently about 100 sparks per minute per precipitator section. Pronounced improvements in precipitator performance have resulted from readjustment of voltages to conform to these new results.

A number of methods have been used for rating precipitation rectifier equipment, but the most useful and significant method appears to be to specify the peak voltage, V_p, the average current, I_{av}, and the average power output, P_{av}, of the set. The average power input to the precipitator may be conveniently calculated by the approximate formula

$$P_{av} = \frac{V_p + V_m}{2} \cdot I_{av}$$

where, in addition to the quantities already defined, V_m = minimum value of the precipitator voltage wave. This formula gives values accurate to about 5 per cent, which is close enough for most purposes.

Combination Mechanical and Electrostatic Collectors

Although combination mechanical-electrostatic gas-cleaning systems have been used successfully for thirty years or more in a number of fields, including carbon black collection, for example, their application to fly ash dates only from about 1946. Several types of mechanical collectors have been used for this service, including small-diameter cyclones or centrifugal separators, skimmer-type cyclones and various inertial cone and louver-type separators. Combination collectors may be arranged with the mechanical unit either preceding or following the precipitator, but in certain applications one type of arrangement may be preferred over the other. Good results have been obtained with both arrangements.

The required operating power for mechanical collectors is supplied indirectly by the station fans or blowers, and appears immediately in the form of draft loss across the collectors and ultimately in frictional heating of the gas stream.

The most important technical arguments which have been advanced in favor of combination collectors are: (1) combination units provide complementary large- and fine-particle collection characteristics, (2) their efficiency characteristics with variable gas flow are also complementary and more uniform, (3) improved gas flow distribution to the precipitator is obtained when a close-coupled mechanical collector is used ahead of the precipitator and (4) in the event of failure of some of the precipitator sections there will always be some collection with the mechanical collector.

Arguments cited against the use of combination collectors include: (1) mechanical collectors inherently have high draft losses and therefore are more expensive to operate and involve higher capitalization charges than straight electrostatic collectors, (2) with a mechanical collector ahead of the precipitator, removal of the ash from the precipitator plates is more difficult, and it usually becomes necessary to provide rappers for the corona wires, and (3) mechanical collectors are subject to plugging when boilers are fired with oil due to formation of sticky ash deposits. At present the use of combination units for fly-ash collection seems to be in part a matter of personal opinion or preference.

Basic Information Required

Because fly-ash precipitator design and performance involves a number of important factors and conditions which are external to the precipitator itself, it may prove helpful to summarize the information which should be made available in specifying new precipitators. These data are:

Precipitator collection efficiency.
Normal precipitator gas flow or cfm rating.
Maximum precipitator gas flow or cfm rating.
Steam flow or boiler load rating.
Precipitator gas temperature.
Permissible draft loss in precipitator.
Type of coal and per cent of ash.
Particle size and maximum per cent combustible expected in ash.
Type of furnace and type of burners.
Type of air preheater.
Precipitator location in generating station.
Layout of connecting gas flues.

The value of such information to the precipitator designer, and the advantages accruing to the user, may be appreciated when it is considered that furnace operating conditions, fly-ash characteristics and permissible stack emission conditions all may vary widely from plant to plant, and that best precipitator performance depends on tailoring the design to meet the individual conditions.

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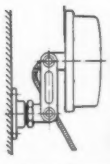

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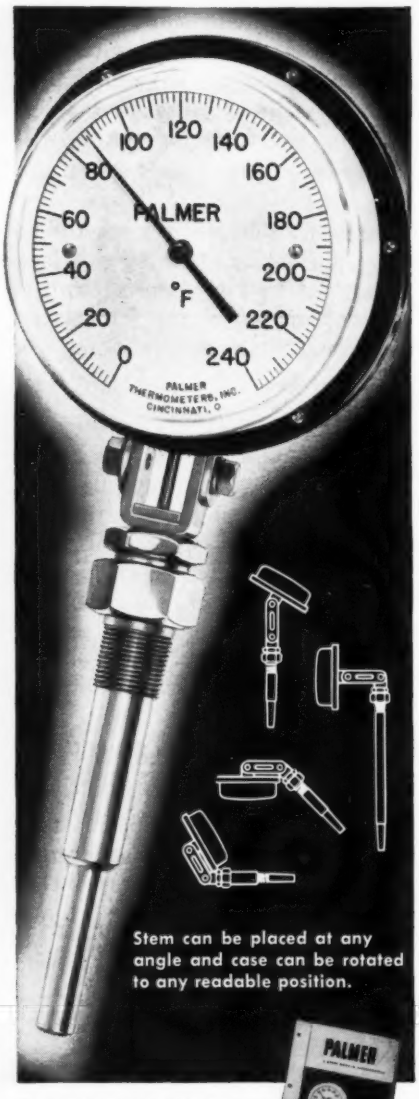

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Facts and Figures

Commercial speeds up to 180,000 rpm have been attained with a-c motors.

•

Fission must take place at the rate of 3.1×10^{10} per second to produce one watt of power.

•

The average man at hard labor will work at the rate of about one-tenth horsepower.

•

The railroads are said to collect over a billion dollars annually for carrying bituminous coal.

•

The United States possesses more than 40 per cent of the world's installed power capacity.

•

Sweden last year put into service a 380,000-volt transmission line which extends from the Harspranget Station in the North to southern Sweden.

•

One-fifth of all the bituminous coal produced in the United States comes from Pennsylvania.

•

Electrostatic precipitators employ peak voltage ranging from 70 to 100 kv.

•

What is said to be the highest lift belt conveyor raises coal 862 ft vertically in 3167 ft in a single 16-deg flight at the Orient No. 3 mine in southern Illinois.

•

With approximately seven per cent of the world's population the United States produces over sixty per cent of the world's annual petroleum output.

•

Steam air preheaters were considered over ninety years ago when James Howden took out a patent abroad for use in the marine field.

•

The natural gas industry has expanded fourfold in the last twenty years.

•

Since the end of World War II, more than a billion pounds of steam generating capacity has been sold by manufacturers of power boilers.

•

The National Bureau of Standards has found that galvanized steel pipe having 3 oz. of zinc per square foot of exposed surface is highly resistant to corrosion in many soils that are very corrosive to bare steel.

•

The safe minimum metal temperature for air preheaters, in order to avoid risk of corrosion with fuels containing sulfur, is generally lower with pulverized coal than with stokers or oil firing.

New Steam Table Up to 700 C*

By DIP.-ING. H. ERYTHROPEL

Essen, Germany

In the November 1952 issue of the German publication *Zeitschrift, VDI*, there appeared a comparison of steam tables published in various countries. These included the familiar American Keenan & Keyes steam tables of 1943, the Japan Society of Mechanical Engineers tables of 1950, the German tables by W. Koch of 1952 and a set of Russian tables prepared by M. P. Wukalowitsch in 1951. The last mentioned are said to be the first steam tables based upon experimental measures up to 600 C, 300 kg per sq in (1112 F, 4266 psia) and calculated to 700 C (1292 F).

TO evaluate thermal calculations in water vapor processes, it is necessary to know the properties of water and water vapor on which they are based. One should therefore have a clear understanding about the steam tables used in various countries and their discrepancies. For this reason the results of studies on the properties of water and water vapor were considered from time to time at international steam-table conferences, establishing standards and tolerances in form of skeleton tables from which the reliability of a steam table could be judged. Such international conferences were held in July 1929, June 1930 and September 1934. The last conference established the standards and tolerances for water and water vapor in the saturated state up to 374 C and 252.22 kg per sq cm (705 F, 3580 psia) for the specific volume of superheated steam up to 550 C and 400 kg per sq cm (1022 F, 5688 psia) and for the enthalpy up to 550 C and 300 kg per sq cm (1022 F, 4266 psia). Within the tolerance system provided there remained a field of variation for establishing the equations from which complete steam tables could be calculated.

Fig. 1 shows the variation of enthalpy values for superheated steam of 500 C (932 F) from the tolerances established at the last steam table conference over a pressure range from 1 to 300 kg per sq cm (14.22 to 4266 psia). No further steam table conferences have been held since international cooperation was interrupted by World War II. Consequently new test results which may be available in various countries have not been generally compared, and no new standards have been established. This is all the more regrettable because there has been increased use of higher steam temperatures in the development of steam power, especially during the last few years, thus adding to the need for establishing the thermal properties over a wider range.

In order to arrive at practical values in the meantime however, the standards established in 1934 were extrapolated without checking their accuracy with the results of more recent tests.

With this in mind it is interesting to study up the steam tables used in various countries today and to compare them, especially in the range of high temperatures. The steam tables available for this comparison are listed in Table 1, together with their range of validity. The

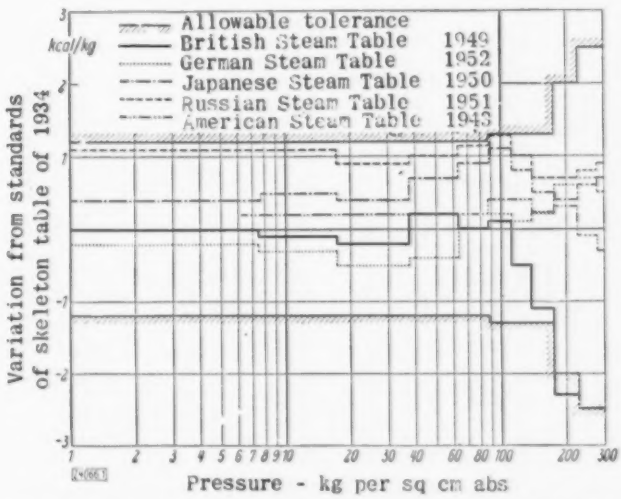
Allowable tolerance
British Steam Table 1949
German Steam Table 1952
Japanese Steam Table 1950
Russian Steam Table 1951
American Steam Table 1943
kcal/kg
Variation from standards of skeleton table of 1934
Pressure - kg per sq cm abs

Fig. 1.—Enthalpy variation in different steam tables for steam at 500 C (932 F) compared to the standards to the skeleton table of 1934

Variation in plus or minus kcal/kg versus pressure in kg per sq cm. Zero line is established standard. Shaded line shows permissible tolerance limit.

values of the enthalpy and specific volume of superheated steam in the range of high pressures and temperatures are of major importance as far as engineering calculations are concerned. Although the values for the specific volume in each steam table, shown in Table 2, show little discrepancy up to temperature as high as 700 C (1292 F,) the values of enthalpy spread considerably in high pressures and temperatures as shown in Table 3.

TABLE 1—RANGE COVERED BY AVAILABLE STEAM TABLES

Country	Date	Thermal Properties of Steam up to Temperature, deg F	Thermal Properties of Steam up to Pressure, Psia
England	1949	1000	3200
Germany	1952	1022	4267
Japan	1951	1112	4267
Russia	1951	1292	4267
United States	1943	1600	5504

These variations will have little influence in calculating condensing plants, but they may assume some im-

* Translated by W. W. Schroedter, Combustion Engineering-Superheater, Inc.

kg/sq cm abs		Temperature°C										
		500	520	540	560	580	600	620	640	660	680	700
1	v	3.635	3,729	3,824	3,918	4,012	4,107	4,201	4,295	4,390	4,484	4,578
	i	833,4	843,6	854,0	864,4	874,8	885,3	895,8	906,4	917,2	928,0	938,8
	s	2,1123	2,1254	2,1383	2,1509	2,1633	2,1755	2,1875	2,1992	2,2108	2,2222	2,2335
5	v	0,7248	0,7439	0,7629	0,7819	0,8009	0,8198	0,8388	0,8577	0,8766	0,8956	0,9145
	i	832,4	842,7	853,1	863,5	874,0	884,6	895,2	905,9	916,6	927,4	938,2
	s	1,9339	1,9472	1,9601	1,9728	1,9853	1,9976	2,0096	2,0214	2,0330	2,0444	2,0558
10	v	0,3611	0,3707	0,3803	0,3899	0,3994	0,4090	0,4185	0,4281	0,4376	0,4471	0,4566
	i	831,2	841,6	852,0	862,5	873,1	883,7	894,4	905,1	915,9	926,7	937,6
	s	1,8563	1,8697	1,8828	1,8956	1,9081	1,9204	1,9325	1,9444	1,9560	1,9675	1,9789
15	v	0,2398	0,2463	0,2527	0,2592	0,2656	0,2720	0,2784	0,2848	0,2912	0,2975	0,3039
	i	830,0	840,4	851,0	861,6	872,2	882,8	893,6	904,3	915.2	926,0	937.0
	s	1,8105	1,8240	1,8372	1,8501	1,8627	1,8750	1,8872	1,8991	1,9108	1,9223	1,9337
20	v	0,1702	0,1841	0,1890	0,1939	0,1988	0,2036	0,2085	0,2133	0,2183	0,2229	0,2276
	i	828,7	839,3	849,9	860.5	871,1	881,9	892,7	903,6	914,4	925,4	936,3
	s	1,7772	1,7909	1,8043	1.8174	1.8301	1,8426	1.8548	1.8668	1,8786	1,8902	1,9016
40	v	0,08822	0,09078	0,09332	0,09584	0,09834	0,10083	0,10331	0,10578	0,10824	0,11069	0,11313
	i	823,5	834,5	845,5	856,5	867,4	878,4	889,4	900,4	911,5	922,6	933,7
	s	1,6955	1,7097	1,7236	1,7371	1,7502	1,7631	1,7756	1,7878	1,7998	1,8116	1,8231
56	v	0,06221	0,06410	0,06597	0,06782	0,06965	0,07147	0,07328	0,07508	0,07687	0,07865	0,08042
	i	819,9	830,7	842,0	853,2	864,4	875,5	886,7	897,9	909,1	920,3	931,6
	s	1,6546	1,6693	1,6835	1,6973	1,7107	1,7236	1,7362	1,7486	1,7608	1,7727	1,7844
59*)	v	0,05892	0,06073	0,06252	0,06428	0,06603	0,06776	0,06949	0,07120	0,07290	0,07460	0,07629
	i	818.6	830,0	841,4	852,6	863,8	874,9	886,2	897.5	908,7	920,0	931,3
	s	1,6481	1.6628	1,6771	1.6909	1,7044	1,7174	1,7301	1,7425	1,7547	1,7666	1,7786
60	v	0,05787	0,05966	0,06142	0,06316	0,06488	0,06658	0,06828	0,06996	0,07164	0,07331	0,07497
	i	818,3	829,7	841,1	852,4	863,6	874,7	886,0	897,3	908,5	919,8	931,2
	s	1,6459	1.6606	1,6749	1,6888	1,7023	1,7153	1,7280	1,7405	1,7527	1,7646	1,7763
64	v	0,05407	0,05575	0,05741	0,05906	0,06069	0,06230	0,06390	0,06548	0,06706	0,06863	0,07019
	i	817,3	828,8	840,2	851,6	862,8	874,0	885,3	896,6	907,9	919,2	930,5
	s	1,6376	1,6525	1,6669	1,6809	1,6945	1,7076	1,7203	1,7328	1,7451	1,7570	1,7688
70	v	0,04919	0,05075	0,05229	0,05381	0,05531	0,05679	0,05826	0,05972	0,06118	0,06262	0,06406
	i	815,6	827,3	838,8	850,2	861,6	873,0	884,3	895,7	907,0	918,4	929,8
	s	1,6259	1,6410	1,6557	1,6698	1,6835	1,6968	1,7096	1,7222	1,7345	1,7466	1,7584
74	v	0,04637	0,04786	0,04933	0,05077	0,05219	0,05361	0,05502	0,05641	0,05779	0,05916	0,06052
	i	814,5	826,2	837,9	849,4	860,8	872,2	883,6	895,0	906,4	917,8	929,2
	s	1,6188	1,6340	1,6487	1,6630	1,6767	1,6900	1,7029	1,7155	1,7279	1,7400	1,7518
80	v	0,04267	0,04407	0,04544	0,04680	0,04813	0,04944	0,05074	0,05204	0,05333	0,05461	0,05588
	i	812,9	824,7	836,4	848.0	859,6	871,1	882,6	894,1	905,5	917,0	928,4
	s	1,6088	1,6241	1,6388	1,6531	1,6670	1,6805	1,6935	1,7062	1,7186	1,7307	1,7426
84	v	0,04050	0,04184	0,04316	0,04446	0,04574	0,04700	0,04825	0,04949	0,05072	0,05194	0,05315
	i	811,8	823,7	835,5	847,2	858,8	870,4	881,9	893,5	904,9	916,4	927,9
	s	1,6025	1,6178	1,6325	1,6470	1,6609	1,6744	1,6875	1,7002	1,7127	1,7249	1,7368
100	v	0,03354	0,03471	0,03585	0,03697	0,03807	0,03916	0,04023	0,04129	0,04235	0,04339	0,04443
	i	807,3	819,6	831,7	843,7	855,6	867,4	879,1	890,8	902,5	914,1	925,8
	s	1,5789	1,5946	1,6099	1,6246	1,6389	1,6526	1,6659	1,6788	1,6915	1,7038	1,7159
110	v	0,03021	0,03130	0,03236	0,03340	0,03442	0,03542	0,03640	0,03738	0,03835	0,03931	0,04026
	i	804,4	817.1	829,4	841,6	853,7	865,6	877,4	889,2	901,0	912,7	924,4
	s	1,5653	1,5815	1,5970	1,6121	1,6266	1,6405	1,6540	1,6671	1,6798	1,6923	1,7044
115	v	0,02876	0,02981	0,03184	0,03184	0,03282	0,03379	0,03474	0,03568	0,03661	0,03753	0,03845
	i	803,0	815,7	828,2	840,5	852,7	864,6	876,5	888,4	900,2	912,0	923,7
	s	1,5589	1,5753	1,5910	1,6061	1,6206	1,6347	1,6484	1,6615	1,6742	1,6867	1,6989
120	v	0,02744	0,02847	0,02946	0,03042	0,03137	0,03230	0,03321	0,03412	0,03502	0,03591	0,03679
	i	801,5	814,4	827.0	839,4	851,7	863,6	875.6	887.5	899.4	911,3	923,1
	s	1,5527	1,5693	1,5852	1,6005	1.6151	1,6292	1,6429	1,6560	1,6689	1,6814	1.6937
125	v	0,02621	0,02720	0,02816	0,02910	0,03002	0,03092	0,03181	0,03269	0,03355	0,03441	0,03526
	i	800,1	813,0	825,7	838,3	850,6	862,7	874,7	886,7	898,6	910,5	922,4
	s	1,5467	1,5635	1.5795	1,5949	1,6096	1,6239	1,6376	1,6509	1,6638	1,6764	1,6887
140	v	0,02306	0,02397	0,02486	0,02572	0,02656	0,02739	0,02820	0,02900	0,02978	0,03056	0,03133
	i	795,6	809,0	822,0	834,8	847,4	859,8	872,0	884,2	896,4	908,4	920,3
	s	1,5298	1,5471	1,5635	1,5793	1,5943	1,6088	1,6227	1,6362	1,6493	1,6621	1,6746
147*)	v	0,02182	0,02269	0,02356	0,02439	0,02520	0,02599	0,02677	0,02754	0,02830	0,02904	0,02978
	i	793,5	807,0	820,2	833,2	845,9	858,4	870,7	883,0	895.2	907,3	919,3
	s	1,5223	1,5398	1 5565	1,5704	1,5877	1,6024	1,6163	1,6285	1,6431	1,6559	1,6684
160	v	0,01977	0,02061	0,02142	0,02220	0,02296	0,02370	0,02443	0,02515	0,02585	0,02655	0,02723
	i	789,5	803,5	817,0	830,2	843.2	855,9	868,4	880,8	893,2	905,4	917,6
	s	1,5087	1.5267	1,5439	1,5603	1,5759	1,5907	1,6050	1 6188	1,6321	1,6450	1,6577
180	v	0,01720	0,01797	0,01872	0,01945	0,02015	0,02083	0,02150	0,02215	0,02279	0,02342	0,02404
	i	783,2	797,8	811,9	825,5	838,8	851,9	864,8	877,5	890,0	902,5	914,8
	s	1,4893	1,5084	1,5263	1,5431	1,5591	1,5743	1,5888	1,6029	1,6164	1,6296	1,6425
200	v	0,01514	0,01587	0,01658	0,01725	0,01790	0,01854	0,01915	0,01975	0,02035	0,02093	0,02150
	i	776,7	791,9	806,6	820,7	834,4	847,8	861,0	873,9	886,8	899,4	911,9
	s	1,4713	1,4911	1,5096	1,5270	1,5436	1,5592	1,5740	1,5884	1,6023	1,6157	1,6287
300	v	0,00895	0,00957	0,01012	0,01066	0,01118	0,01167	0,01214	0,01260	0,01304	0,01346	0,01388
	i	741,6	760,9	778,9	795,4	811,5	827,0	841,9	856,3	870,4	884,1	897,7
	s	1,3892	1,4141	1,4369	1,4581	1,4777	1,4958	1,5126	1,5286	1,5438	1,5585	1,5725

*) interpolated

TABLE 4—SPECIFIC VOLUME, ENTHALPY AND ENTROPY OF SUPERHEATED STEAM ACCORDING TO RUSSIAN STEAM TABLE (WUKALOWITSCH, 1951)

v = specific volume in cu m per kg
i = enthalpy in kcal per kg
s = entropy in kcal per kg deg C

Conversion factors:
Multiply specific volume in cu m per kg by 16.018 to obtain specific volume in cu ft per lb
Multiply enthalpy in kcal per kg by 1.8 to obtain enthalpy in Btu per lb
Multiply pressure in kg per sq cm by 14.22 to obtain pressure in psia
Entropy in kcal per kg deg C is equivalent to entropy in Btu per lb deg F

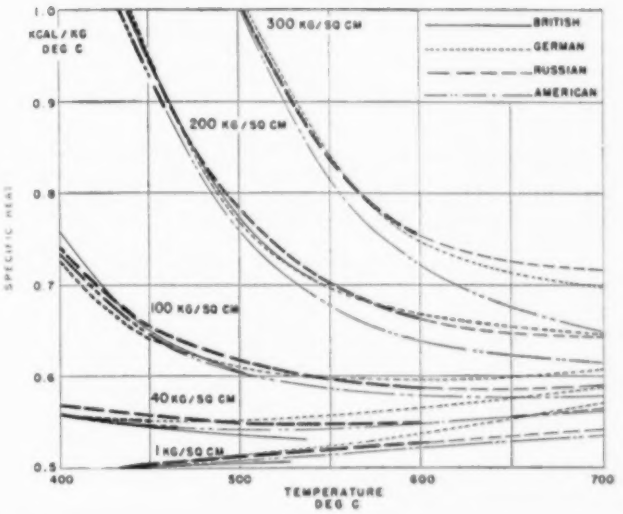

Fig. 2.—Instantaneous specific heat of water vapor according to various steam tables

Specific heat in kcal per kg deg C versus temperature in deg C. Thick lines indicate values confirmed by experiments. Thin lines indicate values determined by extrapolation.

portance in figuring topping units. For an easier comparison the instantaneous specific heats of superheated steam, as calculated for constant pressure from the various steam tables, are plotted in Fig. 2. It can readily be seen by how much the values of the present steam tables vary at high temperatures, further emphasizing the importance of new tests.

The variation between the American and German values can be explained principally by the difference of the temperature influence on the specific heat (at constant pressure) for zero pressure as found by the Americans and by Koch. While the temperature influence is evaluated similarly by the American and the Russian formula, the specific heats nevertheless show discrepancies because of the higher pressure influence at high temperatures found by the Russians in their experiments. The plot also shows the limits of values determined from experimental data and those which were extrapolated.

In this connection the Russian steam table by Wukalowitsch, published in 1951, appears to warrant special interest since, according to its author, the values are based exclusively on test data without extrapolations. In comparison to the earlier tests published, the Russians have apparently used considerably improved test equipment for their new experiments in the thermodynamic properties of water vapor at high temperatures and pressures. This equipment has made it possible to measure thermodynamic properties of steam in an area which could not previously be investigated, namely up to 600 C and 300 atm (1112 F, 4266 psia). These values, therefore, appear to be nearest to the actual properties and can be used as reliable calculating data, at least until further experimental results become available.

The comparison of various steam tables shows that measuring of steam properties at high pressures and temperatures is an important research problem especially since use of constantly increasing steam temperatures requires reliable calculating data. Because of the difficulty of such tests, however, a general evaluation of all experimental data is necessary. It is hoped that international cooperation can be resumed in this field and that it will finally close an obvious gap in the knowledge about the thermodynamic properties of water and water vapor at high temperatures and pressures.

TABLE 2—COMPARISON OF VALUES OF SPECIFIC VOLUME OF SUPERHEATED STEAM AT 700 C (1292 F) ACCORDING TO VARIOUS STEAM TABLES

Pressure, Psia	Specific Volume of Superheated Steam at 1292 F in Cu Ft per Lb			
	Germany*	Japan*	U.S.A.†	Russia
14.22	73.330	73.330	73.346	73.330
568.8	1.8099	1.8107	1.8113	1.8121
1422	0.7096	0.7101	0.7107	0.7117
2844	0.3426	0.3428	0.3436	0.3444
4266	0.2202	0.2204	0.2212	0.2223

* Extrapolated values.
† Interpolated values

TABLE 3—COMPARISON OF VALUES OF ENTHALPY OF SUPERHEATED STEAM AT 700 C (1292 F) ACCORDING TO VARIOUS STEAM TABLES

Pressure, Psia	Enthalpy of Superheated Steam at 1292 F in Btu per Lb			
	Germany*	Japan*	U.S.A.†	Russia
14.22	1692.4	1687.1	1687.0	1689.8
568.8	1683.0	1678.3	1677.1	1680.7
1422	1668.4	1664.3	1660.9	1666.4
2844	1644.1	1639.8	1632.1	1641.4
4266	1619.1	1613.9	1600.9	1615.9

* Extrapolated values.
† Interpolated values.

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Another Large Controlled-Circulation Boiler

The advance in boiler practice during the last 25 years is strikingly illustrated by a contract just closed by Combustion Engineering-Superheater, Inc., to furnish the boiler for a new generating unit at the State Line Station of the Commonwealth Edison Company System. The station is located at Lake Michigan and the Illinois-Indiana border.

Designed around 1926 and officially placed in service in the summer of 1929, this station attained widespread attention because it contained the largest steam turbine in existence—a 208,000 kw, three-element machine operating at 600 psi, 730 F superheat with 500 F live steam reheat and served by six 450,000-lb per hr sectional-header boilers. In fact, this turbine size has not been exceeded to date, although still larger machines are on order.

The new cross-compound turbine-generator now on order will be of 191,000 kw—comparable in size to the earlier unit but it will have only *one* boiler instead of *six*. The nominal steam conditions will be 2000 psig and 1050 F primary/1050 F reheat temperature at the turbine instead of 600 lb, 730 F primary and 500 F reheat. The boiler will be of the now popular Combustion Engineering controlled-circulation reheat type with a twin furnace, platen-type superheater and corner firing with tilting tangential burners for steam temperature control. It will be served by eight C-E Raymond bowl mills and have three air preheaters of the Ljungstrom regenerative type. There will be four circulating pumps and the continuous rated output of the unit will be 1,350,000 lb of primary steam per hour—a figure one-half that of the combined output of the six earlier units supplying about the same turbine capacity.

The new boiler is scheduled for operation in the fall of 1955.

Zirconium Produced for Submarine Reactor

Zirconium, a long known but little used metal, has now been brought into mass production as a material for use in the construction of a submarine nuclear reactor.

Lighter than steel, zirconium, which has been known since 1789, has remarkable corrosion resistance; it has a very high melting point, and is both strong and workable as a structural material. It is found in the sands that wash ashore in many locations but heretofore has been difficult to produce in pure form except at very high cost. Most important for its use in a nuclear reactor is the fact that it does not waste neutrons—the particles that split uranium atoms and keep the atomic engine running. That is, whereas some metals absorb these neutrons and thus interfere with atomic fission, zirconium offers no such interference. This characteristic makes it second only in importance to uranium in the building of a submarine reactor.

When atomic scientists first tackled the assignment of building a submarine reactor, there was not enough usable zirconium to do the job. Then the Atomic Energy Commission gave Westinghouse Electric Corporation the green light to undertake mass production, and a refining plant was built and began full production within 14 weeks with an output of pure zirconium soon reaching several thousand pounds per month.

American Power Conference Program

THE fifteenth annual meeting of the American Power Conference (formerly the Midwest Power Conference) will be held at the Sherman Hotel, Chicago March 25 to 27, inclusive. As in previous years, the conference is sponsored by the Illinois Institute of Technology in cooperation with nine universities and ten local and national engineering societies. It will be under the direction of Prof. R. A. Budenholzer with the preliminary program as follows:

Wednesday, March 25

9:00 am Registration

10:00 am Opening Session. Chairman, R. D. Maxon of Commonwealth Edison Co.; Vice Chairman, F. D. Garvin, Illinois Institute of Technology.

Address of Welcome—Charles Y. Freeman of Commonweath Edison Co.

Address—Dean W. A. Lewis of Illinois Institute of Technology

12:15 pm Luncheon sponsored by ASME. Chairman, James D. Cunningham; Vice Chairman, Eugene Bailey. Speaker to be announced.

2:00 pm Session on Large Steam Generators. Chairman, Prof. H. L. Solberg; Vice Chairman, R. J. Mindak.

"Three Million Kilowatts Operating Experience with Modern Reheat," by Otto de Lorenzi, Combustion Engineering-Superheater, Inc.

"Trends Indicating Possibilities in Future Boiler Designs," by G. W. Kessler, Babcock & Wilcox Co.

2:00–5:00 pm Symposium on Water Problems of American Industry. Chairman, P. W. Swain; Vice Chairman, Prof. J. G. Duba.

"Water Resources of America" (Panel Discussion). J. C. McCabe, L. N. Rowley and B. G. A. Skrotski, all of *Power*.

"Problems of Waste Disposal and Stream Pollution from the Public Standpoint," by E. J. Cleary, Director, Ohio River Valley Sanitation Commission.

"Waste Disposal and Stream Pollution from Standpoint of Industry" by H. W. Gehm, National Council for Stream Improvement.

"The Role of Chlorination in Stream Pollution Control" by A. E. Griffin, Wallace & Tiernan

2:00 pm Electrical Power Transmission Session sponsored by AIEE. Chairman, W. E. Keefe; Vice Chairman F. D. Hurd.

"High-Voltage Power Transmission in the Pacific Northwest," by S. E. Schultz, Bonneville Power Administration.

"Full-Scale Structure Tests of 230-Kv H Frames," by W. A. Schulz, Pub. Serv. Co. of Ind.

2:00 pm Problems of Fuel Conversion sponsored by NAPE. Chairman, Otto Cordes; Vice Chairman, L. F. Clifford.

"Conversion from Coal to Fuel Oil," by G. A. Pardee, Oertel Brewery, Louisville, Ky.

"Conversion from Coal to Gas," by Roger W. Jackson, Western Products, Inc.

3:30 pm Steam Generator Controls, sponsored by ASME. Chairman, J. G. Eilering; Vice Chairman, T. H. Gluck.

"Some Control Circuits for Use of Multiple Fuel Firing on Boilers," by H. Ziebolz, Askania Regulator Co.

"Trends in Combustion and Steam Temperature Control," by Paul S. Dickey, Bailey Meter Co.

3:30 pm Electrical Distribution. Chairman, Prof. M. A. Faucett; Vice Chairman, J. N. Banky.

"Multiple Contingency Outages in Secondary Network Systems," by N. M. Neagle and D. R. Nelson, General Electric Co.

"Overhead Primary and Secondary Distribution Networks," by H. G. Barnett and D. F. Shankle, Westinghouse Electric Corp.

3:30 pm Personnel Training, sponsored by NAPE. Chairman, Gerald Mierendorf; Vice Chairman, Stephen C. Casteel.

"Creating Enthusiasm in Personnel Training," by John E. Conway, A. O. Smith Corp.

"Suggested Improvements in Training Methods," by C. H. Morrow, J. I. Case Co.

"Available Training Programs," by A. H. Nielsen, Wisconsin Electric Power Co.

7:00–10:00 pm Forum—The Industrial Use of Atomic Energy. Chairman, Louis C. McCabe.

"The Atomic Energy Commission's Appraisal," by Gordon E. Dean, Chairman, Atomic Energy Commission.

"Engineering and Technical Problems," by Walter Zinn, Director, Argonne National Laboratory.

"Economic Evaluation," Walker L. Cisler, President, Detroit Edison Co.

"Changes in the Atomic Energy Act," by Oscar M. Ruebhausen, New York Bar Association Committee on Atomic Energy.

Summary by Murray Joslin, Asst. to President, Commonwealth Edison Co.

Thursday, March 26

9:00–12:00 pm Symposium on Large Steam Turbines. Chairman, Ben G. Elliott; Vice Chairman, Harry H. McMeen, Sargent & Lundy.

"Development of the 3600-RPM Turbine," by Homer R. Reese, Westinghouse Electric Corp.

"Factors Influencing the Design and Applications of Large Steam Turbines," by Carl Schabtach, General Electric Co.

"Cross-Compound Steam Turbines for Large Capacity Installations," by Charles D. Wilson, Allis-Chalmers Manufacturing Co.

9:00 am Planning and Economic Analysis. Chairman, Prof. J. A. M. Lyon; Vice Chairman, L. V. LeVesconte.

"A Technique of System Economic Analysis Useful in Long-Range Planning," by H. E. Campbell and E. H. Reilly, Jr., General Electric Co.

"A New Method of Area-Wide Generation Control for Interconnected Power Systems," by N. Cohen, Leeds & Northrup Co.

9:00 am Hydro-Electric Power Session, sponsored by ASCE. Chairman, Frank W. Edwards; Vice Chairman, C. J. McLean.

"Falcon Dam and Power Plants," by J. B. White, International Boundary and Water Commission (United States and Mexico).

"The Guayabo Hydro-Electric Power Development," by E. Montford Fucik, Harza Engineering Co.

9:00 am Water Resources and Water Treatment for Small Plants. Chairman, M. D. Baker; Vice Chairman, Seldon K. Adkins.

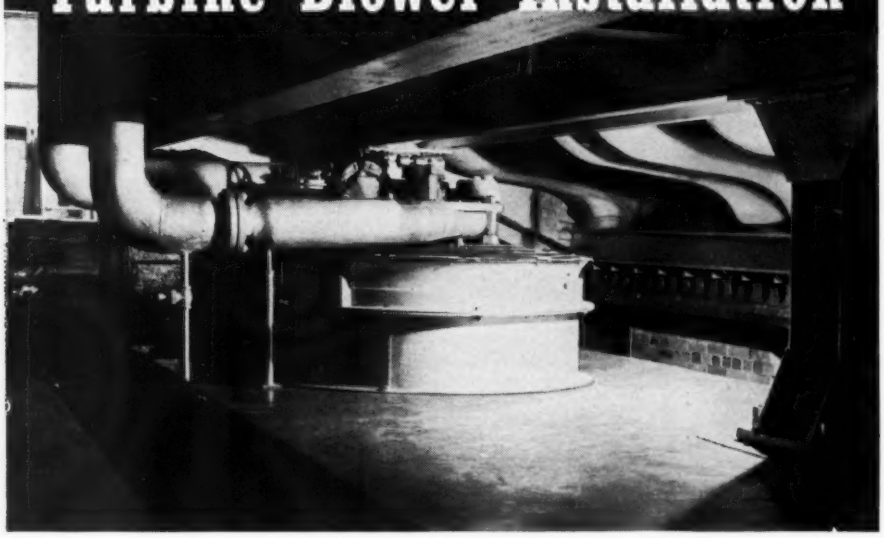
"An Evaluation of Our Water Resources," by Arthur M. Buswell, Illinois State Water Survey.

"Alkalinity Reduction by an Approved Process of Anion Exchange," by A. E. Kittredge, American Water Softening Co.

10:30 am Industrial Power Session, Chairman, A. M. Hopkin; Vice Chairman, V. E. Schlossberg, Inland Steel Co.

"Voltage Flicker from Loads on Electrical Systems," by Marvin Fisher, Jr., University of Illinois.

A COMPACT Turbine Blower Installation



Here is an example of the adaptability of the Wing Turbine Blower to the limitations of restricted space. Additional boiler installations at the E. R. Squibb & Sons, New Brunswick, N. J., plant left little space for auxiliary equipment. As the photograph shows, the complete Wing turbine and blower (47,000 CFM, at 5" s.p., at 1850 RPM) were placed beneath the rear boiler overhang and occupy a space but 54" in dia. by 33" high! (Another Wing unit occupies a similar space 45"x30".)

Compact design is but one of the many superiorities of the Wing Turbine Blower. In addition, they are quiet, rugged in construction, economical in operation and in maintenance. Wing Turbine Blowers cost nothing as a source of power when the oil free exhaust steam is used for process work, space heating or other uses requiring low pressure steam.

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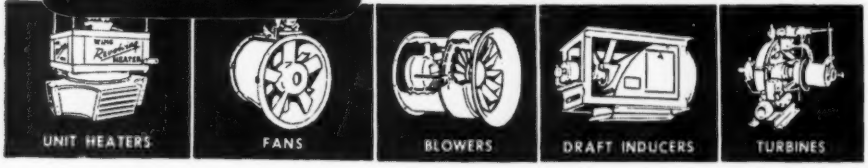


"Arc Furnaces—Light Flicker and Supply Systems," by D. F. Shankle, Westinghouse Electric Corp.

10:30 am Hydro-Electric Power Session, Chairman, Prof. J. G. Tarboux; Vice Chairman, E. A. Cooper.

"The Generation and Use of Niagara and St. Lawrence Power in the Province of Ontario," by Richard L. Hearn, Hydro Electric Power Commission on Ontario.

"The American Development of Power on the Niagara River," by Harold I. Howell, Niagara Mohawk Power Corp.

10:30 am Fuels and Combustion Session. Chairman, Elmer C. Lundquist; Vice Chairman, A. J. Snider.

"Preparation and Combustion of Jet-Pulverized Coal," by C. G. Von Fredersdorff, Institute of Gas Technology.

"Burning of Paper Mill Waste Liquor," by John E. Hoeft, National Container Corp.

12:15 pm American Power Conference Luncheon. Speaker, B. L. England, President, Edison Electric Institute, "The Electric Industry in Perspective"

2:00 pm Symposium on Large Electrical Generators. Chairman, Dean W. A. Lewis.

"Progress in the Design and Application at Large Steam Turbine Driven Generators," by J. B. McClure and C. E. Kilbourne, General Electric Co.

"Inner-Cooling of Turbine-Generators," by J. W. Batchelor, Westinghouse Electric Corp.

"Present Status of Supercharged Cooling," by William L. Ringland and L. T. Rosenberg, Allis-Chalmers Manufacturing Co.

"Operating Experience with Large Generating Units," by Robert P. Liversidge, Philadelphia Electric Co.

2:00 pm Heating of Modern Homes, sponsored by Illinois Chapter of ASHVE Chairman, M. W. Bishop.

"Recent Advances in the Art of Heating Homes," by Prof. Robert W. Roose, University of Illinois.

"Modulating and Load Limiting Controls for Electric House Heating," by Walter F. Friend, Ebasco Services.

2:00–5:00 pm Symposium on Industrial and Institutional Plant Operation, sponsored by NAPE. Chairman, G. Russell Carpenter; Vice Chairman, Jules Bruner.

"Problems of a Paper Mill Plant," by Wyle Austin, Marathon Corp.

"Problems of a Coke Plant," by Jack McBride, Koppers Coke Co.

"Problems of a Penal Institution Plant," by Sal Gran, California State Prison.
"Problems of a Packing House Plant," by Lowell E. Joslin, Krey Packing Co.
"Problems of a State Hospital Plant," by Charles R. Bender, St. Louis State Hospital.

2:00 pm Session on Control of Iron Pickup by Boiler Feedwater. Chairman, R. C. Adams, U. S. Naval Engineering Experiment Station; Vice Chairman, John B. Burkhardt.

"Use of Amines in Low Makeup Steam Plant," by H. J. Guillory, Central Louisiana Electric Co.
"Prevention of Metal Losses in the Wet Steam Areas of Steam Turbines," by Francis L. Archibald, John W. Purssell and Prof. Frederick G. Straub.

3:30 pm Solid and Liquid Fuels Session. Chairman, Prof. Martin Elliott; Vice Chairman Richard C. Corey, U. S. Bureau of Mines.

"Long Range Outlook for Liquid Fuels in America," by Eugene Ayres, Gulf Research & Development.
"Use of Low Rank Fuels in the United States," by Louis C. McCabe, U. S. Bureau of Mines.

3:30 pm Heat Pump Research and Applications. Chairman, Dean Ralph G. Owens; Vice Chairman, M. S. Oldacre, Utilities Research Commission.

"Review of Heat Pump Research in Kentucky," by E. B. Penrod and Merl Baker, University of Kentucky.
"The Design and Manufacture of the Heat Pump Water Heater," by T. A. Hodgdon, Harvey Whipple, Inc.

6:45 pm All Engineers Dinner
Presiding: J. T. Rettaliata, Pres., Illinois Institute of Technology.

Friday, March 27, 1953

9:00 am Residential Air Conditioning Session. Chairman, L. G. Miller; Vice Chairman, G. G. Freyder.

"Promoting the Installation of Residential Heat Pumps," by George S. Whitlow, Union Electric Co., St. Louis.
"New Application Techniques Improve Residential Air Conditioning," by E. P. Palmatier, Carrier Corp.

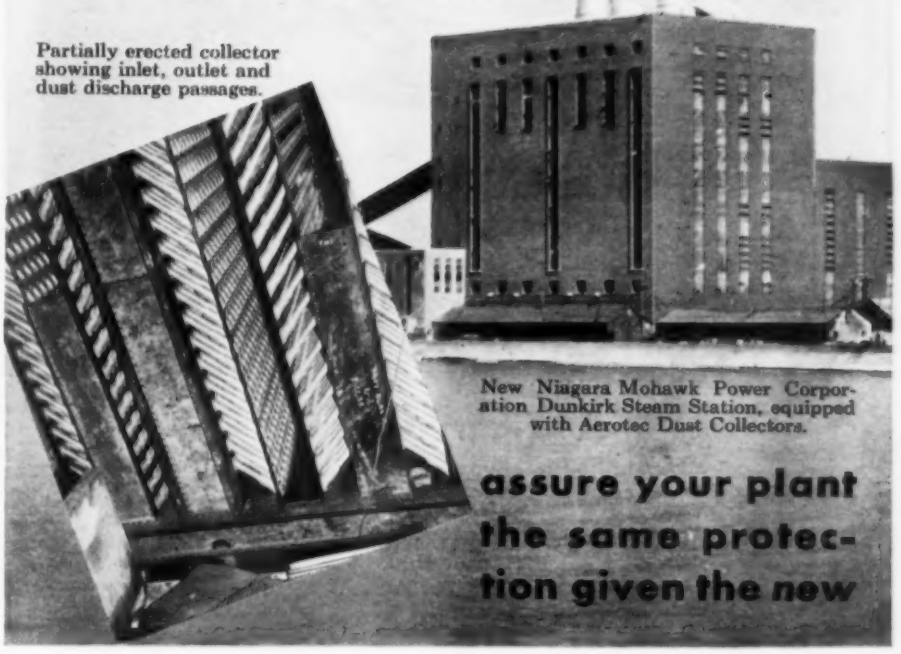
9:00 am General Interest Session. Chairman, G. Ross Henninger, Iowa State College.

"Are Federal Power Practices Sound National Policy?" by E. Robert de Luccia, Pacific Power & Light Co.
"The Materials Situation as Related to the Power Industry," by J. F. Moore, Ebasco Services, Inc.

9:00 am Characteristics of Ion Exchange Resins Session.

high efficiency AEROTEC

DUST COLLECTORS



Partially erected collector showing inlet, outlet and dust discharge passages.

New Niagara Mohawk Power Corporation Dunkirk Steam Station, equipped with Aerotec Dust Collectors.

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At the new Dunkirk Steam Station of Niagara Mohawk Power Corporation, two reheat steam generators of 670,000 lb. per hour capacity are pulverized fuel-fired. Dust collection for this station is handled by Aerotec, Design 3 RAS Collectors, and a duplicate system is under construction for the new Albany Steam Plant . . . making a total of eleven Niagara Mohawk boilers to be equipped with Aerotec Dust Collectors.

The collectors for Dunkirk and Albany consist of 84 "Unit Building Block" elements completely assembled at the factory for easy erection in the field. The small diameter tubes, of permanent molded aluminum construction, have proved their extremely high collection efficiency and long life on hundreds of installations. Their light weight cuts steel requirements for supporting structure, and makes possible roof installations with a minimum of reinforcement. The light weight tubes also reduce erection costs.

Aerotec efficiencies meet or exceed the requirements of most dust ordinances today. Evenly spaced tube outlets provide excellent inlet flow conditions for an AEROTEC electrical secondary—should future ordinances require still higher efficiencies.

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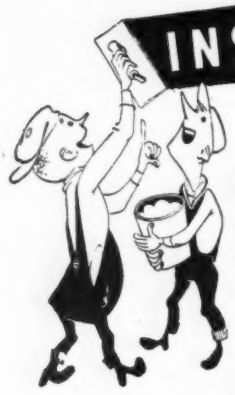

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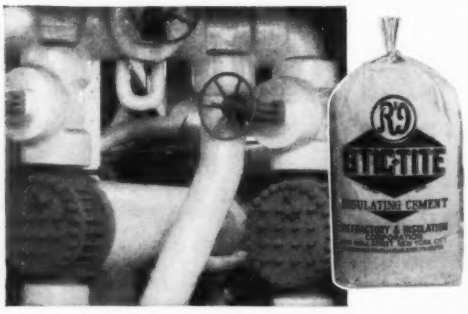

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Sponsored by ASME. Chairman, Louis Wirth; Vice Chairman, W. W. Tomes.

"Acid Regeneration of Cation Exchangers," by F. K. Lindsay, National Aluminate Corp.

"Factors Influencing the Operation of Anion Exchange Resins," by Francis X. McGarvey and J. Thompson, Rohm & Haas Co.

"Characteristics of Mixed Bed and Two-Step Ion Exchangers," by M. E. Gilwood and C. Calmon, The Permutit Co.

9:00 am Diesel Engines Session. Chairman, W. P. Green; Vice Chairman, R. L. Stanley.

"Opposed Piston Dual-Fuel Engines," by E. L. Dahlund.

10:30 am Session on Residential and Commercial Heat Pumps. Chairman, W. T. Reace; Vice Chairman C. M. Bernam, Jr.

"The Air-to-Air Residential Heat Pump," by Gerald L. Biehn, Westinghouse Electric Corp.

"Commercial Year-Round Air Conditioning with the Heat Pump," by Philip Sporn, and E. R. Ambrose, American Gas and Electric Service Corp.

10:30 am Electronics Applications Session. Chairman, G. E. Foster; Vice Chairman, Paul Glass.

"Use of Carrier Spectrum," by T. A. Cramer, General Electric Co.

"Survey of Power Plant Electronics and Resulting Maintenance," by Harold L. Garton, Commonwealth Edison Co.

10:30 am Gas Turbine Combustion Problems. Chairman, Newman A. Hall; Vice Chairman, R. A. Schmidtke, Illinois Institute of Technology.

"Combustion in Gas Turbines," by Herbert R. Hazard, Battelle Memorial Inst.

"Corrosion Aspects of Bunker 'C' Combustion in Gas Turbines," by B. O. Buckland and C. M. Gardiner, General Electric Co.

12:15 pm American Power Conference Luncheon. Sponsored by Western Society of Engineers. Chairman, Ovid W. Eshbach; Speaker, E. B. Newill, General Motors Corp.

2:00–5:00 pm Symposium on Gas Turbines. Chairman, John L. Yellott, Locomotive Development Committee; Vice Chairman, Y. S. Yampolsky, Armour Research Foundation.

"A Regenerative Gas Turbine Generator for Central Station Service," by H. C. Davis, Texas Power & Light Co. and R. L. Jackson, General Electric Co.

"Development and Application of Gas Turbines for the Oil and Gas Industry," by T. P. Latimer and J. K. Hubbard, Clark Brothers.

"Turbo-Jet Aircraft Engines," by Dimitrius Gerdan, General Motors Corp.

2:00–5:00 pm Economics of Evaporation and Demineralization. Chairman, Robert Participants:

G. Gall, Edison Electric Institute; Vice Chairman J. D. Yoder.

"Economics, the Key to Evaporation vs. Demineralization for Makeup in High-Pressure Steam Power Plants," by E. B. Morris and C. E. Brune, American Gas and Electric Corp.

"Evaporation for Treatment of Makeup," by A. M. Impagliazzo, Griscom-Russell Co.

"Performance of a Complete Demineralization Process for High-Pressure Boiler Makeup water," by A. B. Sisson, Public Service Company of Northern Illinois.

2:00–5:00 pm Symposium on Network Analyzers. Chairman, E. T. B. Gross. Participants:

Glenn W. Bills, Bonneville Power Administration; J. W. Nilsson, Iowa State College; Ralph D. Goodrich, Bureau of Reclamation; John S. Denison, Texas A & M College; James B. Ward, Purdue University; George P. Wilson, Jackson & Moreland Engineers.

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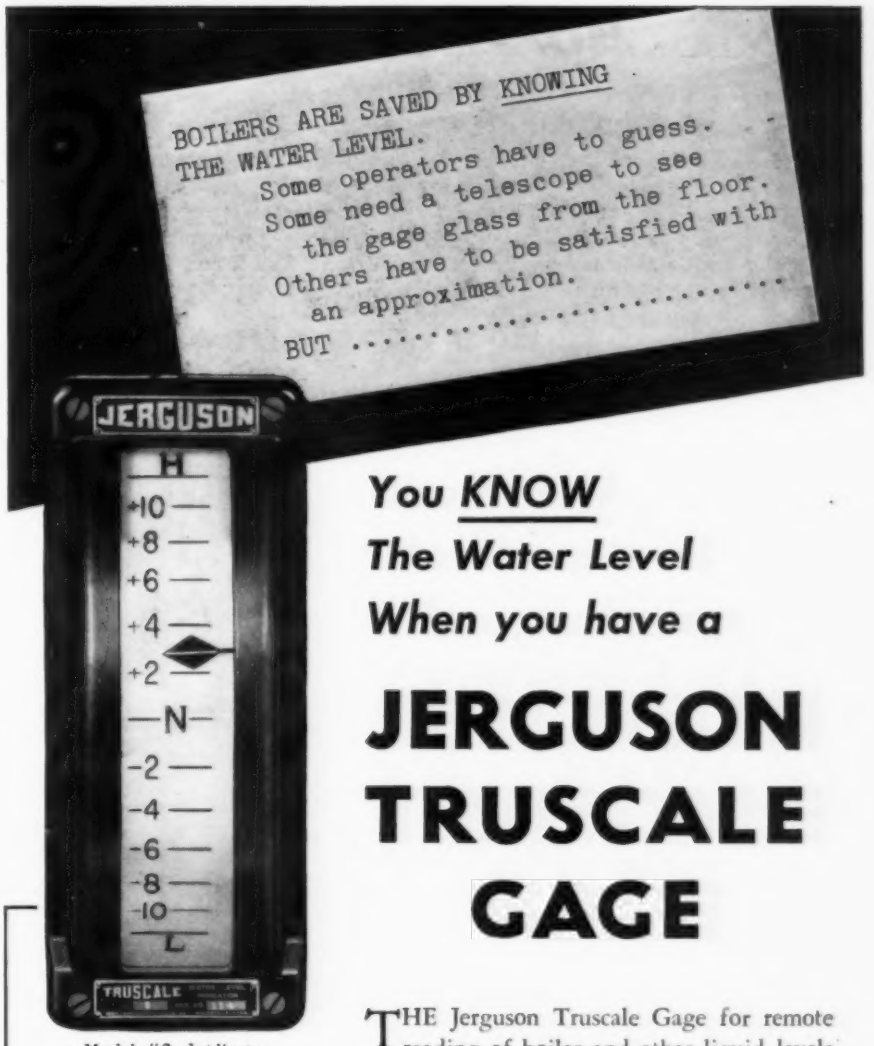

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Bokaro Placed in Service

THE Bokaro steam power plant, the first section of India's 140-million dollar multi-phase power system, modeled after our TVA and a product of American engineering design and equipment, was formally dedicated by Prime Minister Nehru on February 21. This plant, which is not only the largest in Asia but the first major high-pressure steam station in the Far East, will be linked to a series of dams for hydro power, irrigation and flood control in the 330-mile long Damodar Valley in eastern India. A total of 477 miles of transmission lines and numerous substations are involved with the Damodar Valley Corporation, a government-financed utility, operating the system.

Initial Capacity 150,000 Kw

This steam plant initially contains six 300,000-lb per hr steam generating units of the Combustion Engineering two-drum radiant type designed to operate at 895 psig and 910 F at the superheater outlet, each supplied with pulverized coal by two C-E Raymond bowl mills. There are three 50,000-kw turbine-generators of the General Electric tandem-compound, double-flow type with hydrogen-cooled generators, each unit being served by two boilers. Provision has been made in the present building for the installation of a fourth unit which will bring the capacity up to 200,000 kw. Only the first unit is now in service, but operation of the others has been scheduled to follow at three-month intervals.

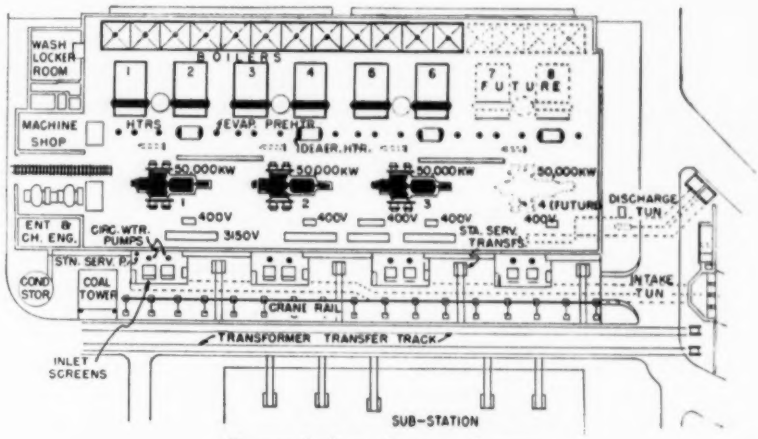
The coal which the plant has been designed to burn averages 45 per cent fixed carbon, 25 per cent volatile, 4 per cent moisture, 26 per cent ash and has a heating value of around 10,750 Btu per lb. The ash-fusion temperature is about 2400 F.

Industrial Area Served

This Damodar Valley project centers in one of the most highly industrialized regions of India containing about 85 per cent of the world's best mica, 75 per cent of India's coal deposits, most of its iron ore, and large deposits of manganese, copper, limestone, bauxite, asbestos and chrome. Jamshedpur, "India's Pittsburgh," is expected to take substantial amounts of power from the system and the transmission lines will carry power from Damodar to Calcutta, India's largest city, some 200 miles away. It is anticipated that the steam plant will carry the base load thirty-seven weeks of the year and the hydro plants will take over the bulk of the load during the fifteen weeks of monsoon weather (rainy season).

A general view of the station as it appeared when dedicated is shown on the cover of this issue, and a plan of the powerhouse showing the equipment layout is here shown.

The Kuljian Corporation of Philadelphia designed and constructed the station and will operate it for a year before turning it over to the staff of Indian engineers who have received extensive training in the United States. The prime contractor in the purchase of the American equipment was International General Electric Company.



General plan of power house

Prime Minister Nehru of India addressing the assemblage at the plant dedication on February 21

New Books

Any of these may be secured by writing Combustion Publishing Company, 200 Madison Avenue, New York 16, N. Y.

Economics of Natural Gas in Texas

By **John R. Stockton, Richard C. Henshaw, Jr., and Richard W. Graves**

This book of 316 pages was prepared under the direction of the Bureau of Business Research, University of Texas, of which Mr. Stockton is director and Mr. Henshaw its statistician. Mr. Graves, a former member of its staff, is now associated with Tulane University.

Although emphasizing the role of natural gas in Texas economy, the text is national in scope, in line with the widespread extension of pipe lines and the unparalleled increase in gas consumption. As such it contains a wealth of information aimed at meeting a broad reader interest and providing a comprehensive reference. To this end, there are 87 tables, together with 57 charts and illustrations, containing information on natural gas reserves, production, transportation and utilization, both as a fuel and in various processes.

Despite the fact that the treatment is primarily economic, related technical topics are discussed, as is also the position of natural gas in relation to competitive fuels. The chapters on taxation and public control will be found both interesting and informative.

While a vast amount of material has been published from time to time on natural gas in magazines, technical papers, etc., much of it is widely scattered and not readily obtainable. Therefore the present book offers a comprehensive, factual treatment of the subject that should prove most useful.

The price of the book is $5.

Heat Transfer Phenomena

By **R. C. L. Bosworth**

This book is concerned with the conduction of heat in gases, radiative transfer, conduction in solids and liquids, forced and natural convection, heat flow with simultaneous phase change and the use of model methods. The author has based his presentation upon the treatment of the flow of heat as a transport process in which one or more physical characteristics of a molecular assembly may be transferred from point to point by the movement of certain carriers."

The initial chapter gives a classification of transfer processes, following which thermal conductivity of gases, thermal radiation and thermal conduc-

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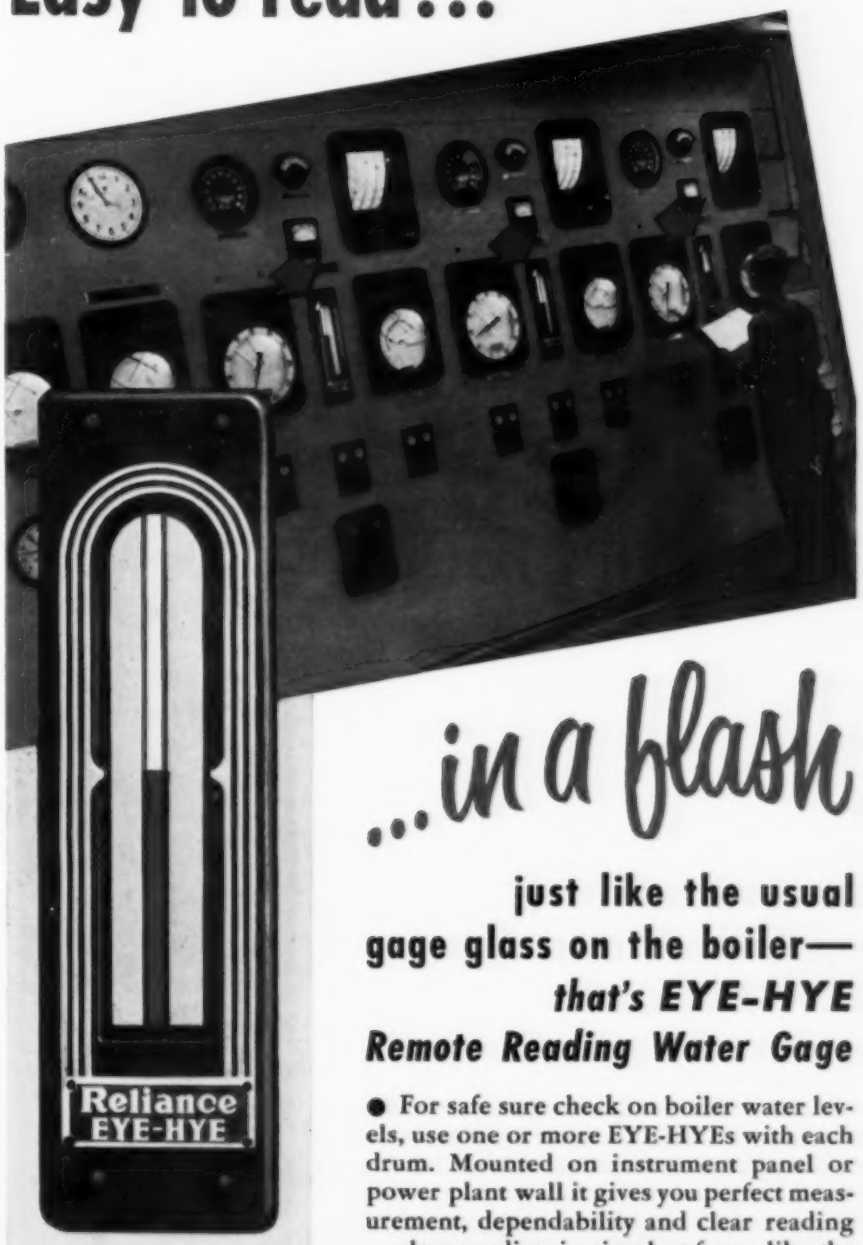

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Brush-applied to drums, tubes, waterwalls, economizers, circulators and associated power equipment exposed to steam and boiler water, Apexior Number 1 provides essential dual protection. The barrier Apexior erects against corrosion provides also a surface that stays clean longer and cleans more easily, thereby assuring more efficient performance in service — less costly maintenance out-of-service. These are the reasons why today Apexior Number 1 remains . . . the Number-1 aid to good boiler housekeeping.
Dampney formulates, in addition to Apexior, other coating materials likewise engineered to meet specific equipment-protection needs. Let us serve as your Number-1 consultant whenever you must have a right-the-first-time recommendation on any specialized metal-maintenance requirement.
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tivity in condensed phases are taken up. Succeeding chapters discuss natural convection, forced convection (or simultaneous transport of heat and momentum), simultaneous transport of heat and mass, the use of the equivalent electrical circuit, and thermodynamical similarity.

The mathematical approach to heat transfer is a rather rigorous one, and consequently this book should be primarily of interest to the heat transfer specialist, the graduate student in physics or mechanical engineering, and those concerned with theoretical aspects of the design of heat-transfer equipment. The author has expanded material originally prepared for a Conference on Heat Transfer held at Sydney, Australia, in August 1948 under the auspices of the Institute of Physics, Australian Branch.

The book, which is probably the first Australian technical work to be published simultaneousy in that country, Great Britain and the United States, contains 212 pages and sells for $6.

Thermodynamic Properties of Nitrogen

The cost of transmission of natural gas per Btu unit is directly influenced by the concentration of nitrogen which, as a high molecular weight constituent increases the power required for pumping. Proposals have been made to remove nitrogen prior to transmission as a means of increasing pipeline effectiveness. Further, the removal of propane and ethane from high-nitrogen natural gas for petrochemical manufacture requires the removal of nitrogen to insure maintenance of heating value requirements on the gas. Also, the storage of liquefied natural gas for meeting peak loads requires separation of the nitrogen to insure uniformity of the natural gas when removed from storage.

The engineering design of plants to separate nitrogen from natural gas requires accurate data on the thermodynamic properties of nitrogen over a wide range of conditions. Previously published charts either cover an inadequate range of pressure or suffer from scale modulus limitations. To provide charts of value to the natural gas industry, researchers at the Institute of Gas Technology, affiliated with Illinois Institute of Technology, have recalculated the usual thermodynamics properties of nitrogen on the basis of more recent fundamental data from the published literature.

"Thermodynamic Properties of Nitrogen," by O. T. Bloomer and K. N. Rao, IGT Research Bulletin No. 18, presents the properties in tabular form and as charts of enthalpy vs. entropy, and of compressibility factor as a func-

tion of temperature and pressure. The range of the tables and charts is from saturated liquid at −320.4 F to superheated vapor at 500 F, and pressures from 10 to 1500 psia. Properties tabulated are specific volume, enthalpy, entropy and the fugacity-to-pressure ratio. For the superheated vapor region, calculations were based on zero-pressure specific heat data and a new equation of state.

As a supplement to the bulletin, the "Mollier Chart for Nitrogen" and "Compressibility Chart for Nitrogen" have been reproduced full scale (grid 10 × 10 to the inch) on heavy paper, 22 × 34 in. They are issued as a set only (two sheets) and are sold separately from the bulletin which is priced at $3.50.

Code for Protection Against Lightning

Despite the value of lightning rod systems for protecting buildings, their use has not proved as effective as possible because of a general lack of information as to the best methods of protection. To enable the public to demand installations designed for adequate protection, the National Bureau of Standards has just issued a new edition of its "Code for Protection Against Lightning," sponsored jointly by the National Fire Protection Association, American Institute of Electrical Engineers, and the NBS.

Widespread ignorance regarding proper installation practice has resulted in great variations in lightning protection both of buildings and of electric equipment and, consequently, in installation of many inadequate systems. This handbook emphasizes personal precautions and protection of buildings and miscellaneous structures.

In addition to including material revised from previous handbooks, the volume contains information on aluminum as a suitable material for lightning protective systems, new rules on vents and stacks emitting explosive dusts, vapors, or gases, and detailed specifications for lightning rods.

This 88-page booklet, with paper cover, is attainable from the Government Printing Office, Washington 25, D. C., for 40 cents.

To Guide Burma Research

The Armour Research Foundation of Illinois Institute of Technology has just signed a three-year contract to reorganize and expand the State Industrial Research Institute of Burma in Rangoon. The principal objectives will be to train scientists, engineers and technicians, and to set up research and development programs. The Burmese Institute is located on the campus of Rangoon University.

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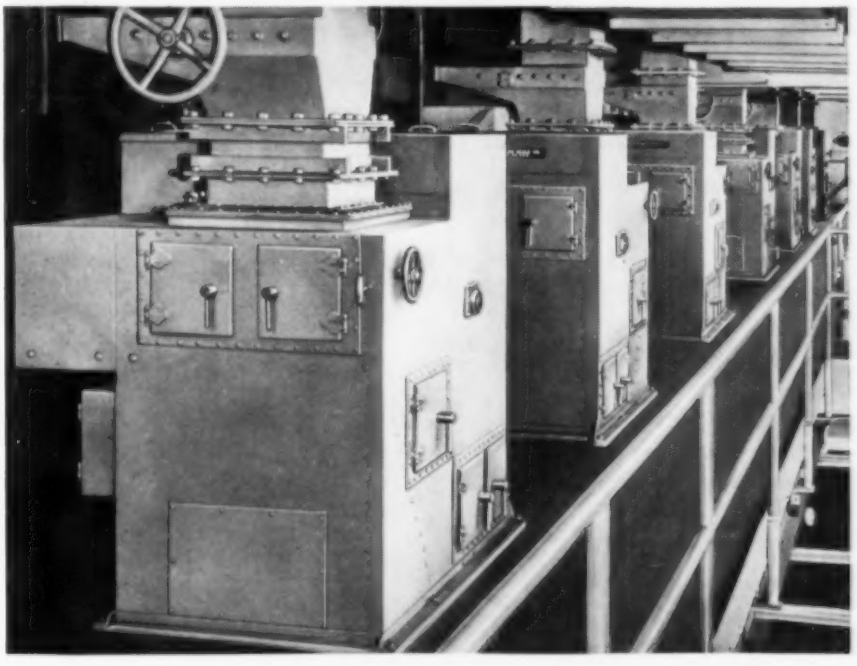

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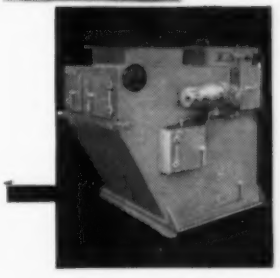

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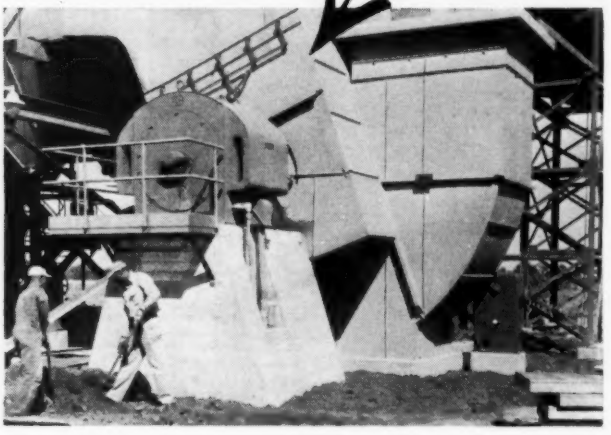

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John Hunter Passes

Many older engineers among COMBUSTION readers undoubtedly hold vivid and kindly recollections of John Hunter who, we learn, passed away at his home in Winter Park, Fla., on February 5 at the age of 87. Previous to his retirement in 1939, Mr. Hunter had been active and widely known in both marine and stationary power circles.

Born in Girvan, Scotland, August 11, 1866, he was educated at Hawthorne Academy, London, and then served an apprenticeship in mechanical engineering and shipbuilding. He then went to sea as a junior engineer on the old Red Star liner "Westernland," and became first assistant engineer on the "Friesland" of the same line. Subsequently in 1895 he joined the American Line as first assistant on the then new liner "St. Louis" and served on her sister-ship the "St. Paul" as chief engineer during the Spanish-American War when she was operated by the U. S. Navy.

Leaving the sea in 1904, Mr. Hunter joined the Union Electric Light & Power Company of St. Louis as chief engineer of its system, and while there took an active part in the formation and work of the Prime Movers Committee of the old National Electric Light Association. He became associated with the late Hugh L. Cooper in construction of the Keokuk Dam and power development on the Mississippi, and when World War I broke out in 1917 he was called to government service in organizing the shipbuilding program and later served as naval constructor in charge of the Standard Shipbuilding Company. Following termination of the war he joined the Heine Boiler Company as chief engineer, which position he held till 1925 when he established a consulting engineering practice.

Long an active member of the ASME, Mr. Hunter served on many committees including that of the Boiler Code and was manager and later vice president of the Society in 1917–1919. He attained the grade of Fellow in 1939. He was a fellow of the Florida Engineering Society, and a past president of the Engineers Club of St. Louis.

Charles A. Booth

Charles A. Booth, Executive Vice President of Buffalo Forge Co., died last month in Buffalo General Hospital after a short illness at the age of 76. A graduate of Worcester Polytechnic Institute, he started with Buffalo Forge Co. in 1900, became sales manager in 1907, and later Vice President and Director. He was a Past President of the National Association of Fan Manufacturers, a member of the ASME and of the ASHVE.